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THESIS

An Integrated Facility for Municipal Solid Waste Disposal, Electrical Generation, and Desalination

by

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Master's Thesis

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ABSTRACT

An Integrated Facility for Municipal Solid Waste
Disposal, Electrical Generation, and Desalination

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A preliminary design was completed for a facility that uses municipal solid waste as fuel for generating electricity and cogeneration steam for a seawater desalination unit. An average city of 100,000 population is the basis of the design. The design showed that heat from the combustion of municipal solid waste will provide nearly 2% of per capita electrical power needs and 7% of fresh water requirements. This thesis proposes a new arrangement of known technologies for use in Public Works. The United States is facing increasingly complex problems with the management of mounting quantities of Municipal Solid Waste. Developing new power plant sources for electrical generation now requires searching for scarce energy resources and regularly contends with great opposition. Lastly, lack of fresh water supply has become a prime concern to many cities. Most often the organizations responsible for the management of Solid Waste, Electrical Generation, and Water Resources operate independently focusing primarily on separate requirements. Within this thesis it is demonstrated that a collective effort among these three fundamental infrastructures can benefit all.

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INTRODUCTION

The primary objective of this thesis is to design a unique facility. The integrated plant will dispose of Municipal Solid Waste (MSW) in an incinerator, generate electricity and produce potable water from seawater. Power plants that use MSW as fuel are already proven designs. Seawater desalination using heat extracted from an electrical generation turbine is also a proven technology. The objective of this thesis is to connect MSW combustion, electrical generation and seawater desalination into one efficient operation. A unique arrangement of equipment for producing electricity and providing heat for desalination to produce fresh water is presented. This facility requires <u>no</u> imported fuel source other than MSW to sustain operation and requires no imported electricity to sustain operation and requires no external water source for operation other than ocean water.

The approach used to design the facility incorporated expanded research to meet secondary objectives. First, numerous professional journals were researched to determine how much MSW management, electrical utilities and water resources are in need of this proposed facility. There is no sense in designing a plant that has no place for use or has an insupportable benefit/cost ratio. Secondly, two important plants were visited to gain specific knowledge of mechanical components and thermodynamic interface. One was the combined electrical generation/desalination facility in Guantanamo Bay, Cuba. There are only a few of these facilities in existence worldwide. The second plant visit was one of the nation's top MSW electrical generation plants in Salem, Oregon. A thorough understanding of the design of each facility resulted from the extensive visits. Information from the site visits and several design manuals were used as background material for this thesis. Also, while in Guantanamo Bay considerable demographic engineering data was retrieved for designing and proposing the construction of a pilot facility.

An important point about this thesis is that economical analysis is not the greatest emphasis. Much will be written on the financial aspects, but there are far more significant and not readily measurable intangible costs on society associated with domestic waste, electrical generation, water resources and pollution. The dynamic politics involved in the deregulation of electricity sales is rapidly progressing. Just a brief reading of the "World Cogeneration" circular published every two months provides lengthy, detailed updates on deregulation of utility sales. The often referenced acronyms of federal statutes, agencies and policies are enough to keep a reader confused. The Public Utility Regulatory Act of 1978, the Clean Air Act Amendment of 1990, the Energy Policy Act of 1992, and the

Federal Energy Regulatory Commission name only a few. Any monthly issue of the Pollution Engineering magazine also is deluged with ever changing federal laws such as the Clean Water Act. Furthermore, each state has its own complex regulatory mechanisms. Also, this paper is not a engineering marvel that offers new thermodynamic discoveries. The fundamental engineering principles referred to are all well established accepted working truths.

This thesis is a presentation only on domestic waste which today is ordinarily be deposited in municipal waste landfills. That is to say ordinary municipal waste that is not classified as hazardous waste.

The focus is on needs and solutions for the United States of America not the planet as a whole. A correlation is made to some successful programs in other parts of the world.

Domestic waste will forever continue to be generated in rather large volumes. There is stiff opposition to the development of any new landfills, or in many cases, even the continuing use of existing landfills. This was demonstrated by the successful blocking of plans developed by Waste Management Inc, to build a landfill 95 miles southwest of Spokane to receive Seattle's garbage, despite the economic benefits offered to the host, Adams County. True meaning is given to the cliché "you can't have your cake and eat it too". The will of the public is not to have solid waste landfills contaminate fresh water resources. Nor is it desirable to have gases generated by landfills pollute the air. Mandates have resulted in costly geosynthetic liners to prevent leachate problems and encapsulation with long term monitoring to reduce air pollution. Along with these requests of the public they require that taxes to pay for such practices will not increase the total tax burden.

For a multitude of reasons the public does not want to see precious land consumed by landfills. Dumping or sinking garbage in the ocean is not wanted. Shooting it into outerspace is absurd. Sending garbage to the north or south pole will not be tolerated. There is still considerable debate on the effectiveness of source reduction and recycling. Even if these two are successes, they only reduce the problem slightly and they rely heavily on constant public training, desire, participation of the masses and enforcement.

Combustion of MSW is also opposed. MSW combustors pollute air and the 5 percent residual ash is toxic as pointed out by opponents. The fact remains that in the foreseeable future garbage will continue to be discharged from every household, business and manufacture.

Power plants utilized to produce electricity also face great opposition. Generally, citizens refuse to live without electricity, but the manner of its production is contested. Solar

energy, wind energy, ocean tidal action, etc. may never come close to satisfying the ever-increasing electricity demands of the United States. Nuclear, fossil fuel, hydroelectric or MSW combustion are the primary remaining alternatives.

Perhaps the last nuclear power plant in this country has been constructed.[1] A few of the public complaints are radiation leaks, accidents, water contamination, disposal of spent fuel, and decommissioning costs.

Fossil fuel electrical generation plants present various concerns. Air pollution and adverse effects of using fresh water for cooling are denounced by opponents. Coal mining is a travesty for a number of reasons in the opinions of many Americans. The USA has essentially run out of well drilling options for crude oil without offshore operations or the far north being allowed. The reliability of imported oil at any future date may be questionable. Hydropower-produced electricity seems to have reached a level of maximum tolerable usefulness in North America. Two recent cited cases of this attitude are the opening of flow in the Columbia River dams in the Northwest[2] and the cancellation of the largest power project in North America, the Great Whale River Canadian dam project.[3] There are numerous reasons for this turnabout which will be discussed later. Waste-to-Energy is a viable choice to supplement electrical generation.

The availability of fresh water has without a doubt emerged to the forefront of national attention in recent decades. If we continue to siphon off upstream water in large quantities by the turn of the century some hydroelectric dams won't have sufficient flow to function. Miami is now in a fresh water crisis. Due to increasing population and agriculture the Everglades are being drained. The Midwest aquifer is being depleted at a phenomenal rate as a result of extensive "well circular irrigation". Houston experienced measurable losses of geotechnical stabilization caused by water wells. Los Angeles is scrambling for solutions to its lack of fresh water.[4]

This thesis proposes a single facility to best accommodate domestic solid waste disposal, electrical generation and fresh water production. Chapters 1 to 3 summarize the current status of MSW, electricity generation/consumption and water resources in the USA. Chapter 4 explains how the proposed facility will function <u>and</u> provides details on the net positive/adverse impacts of its operation on the environment and utilities infrastructure of America. Chapter 5 provides the technical specifications and capacities for a plant supporting the "average" American city of 100,000 population. Chapter 6 proposes Guantanamo Bay, Cuba as the location for the first plant and explains why. Chapter 7 is a "thesis level" design of a plant proposed for Guantanamo Bay. Chapter 8 suggests regions (cities) most applicable and suited for this plant.

SECTION I
"The Problem"

CHAPTER ONE
MUNICIPAL SOLID WASTE LANDFILLS

The USA has implemented and is experiencing success with recycling programs and source reduction. Unfortunately, these programs have limits on the total achievable impact on reducing nonhazardous waste destined for landfills.

Volume related to population increases

In the United States, about 50,000 pounds of waste is produced for each of our 240 million residents every year.[5] Approximately 3 or 4 percent of that total solid waste is produced directly by the American household. This results in over 200 million tons of municipal solid waste each year, with estimates showing this amount increasing by slightly more than one percent a year. Though U.S. population has soared, garbage output per person has increased even faster: Since World War I, the American population has grown by 34 percent, while solid waste has shot up 80 percent. With per capita garbage generation rising from 2.7 pounds a day in 1960 to 4.0 pounds a day in 1992, household waste has grown more than twice as fast as the population during the last few decades.[6] Projections state that this trend is likely to continue with garbage generation expected to be 4.9 pounds per person per day by 2010.[7]

Space concerns:
Public opposition against the proposals of any new landfills or expansion of existing landfills continues to intensify. Numerous cases are on record throughout the country of public protests successfully halting the development of landfills. The "Not in My Backyard" mentality prevails. Ventura, California has less than two years service life remaining until the maximum capacity of its landfill is reached. Its new advanced technology landfill to be constructed has been canceled because citizens have made it

clear that they will not tolerate another landfill in the county. Serious suggestions were made to truck the waste to Utah. Marion County, Oregon opted for incineration instead of landfilling to dispose of daily MSW from 200,000 residents. Seattle has also strongly resisted accepting any additional landfill sites even when facing two overflowing landfills.

Demographics show that the most dense population concentrations are in coastal states. Land in these regions is valuable and is guardedly used for just about any development other than landfills. Airports, highways, housing tracts, resorts, amusement parks, schools, golf courses, stadiums, national forests, state parks and similar uses are considered to be of the greatest importance. As the immediate vicinities of shorelines fill up, housing communities and businesses simply expand further inland. This is evident by observation of the 100 mile wide megaopolis that extends from north of San Francisco all the way down to Tijuana. Certainly space for landfills is limited in many areas. Ocean dumping is banned and long distance transporting of garbage is cost prohibitive.

If real estate was available for future landfills, the west coast and east coast cities would have to endure living with alarming numbers of nearby landfills in the absence of long distance transporting. Assuming that per capita generation holds steady at 4 pounds per day and population increases by only one percent annually, the volume of waste to be deposed of over the next 30 years is massive.

A conservative estimation of today's population is 240 million.

$240{,}000{,}000(1.01)^{30} = 325{,}000{,}000$ in year 2025

Total weight of 30 years of garbage is
0.5(325,000,000 + 240,000,000)people x 4 lb/person/dy x (30 yr)(365 dy/yr)
x (ton/2000 lb) = 6.2 billion tons

Total landfill compacted volume =
(6.2 billion tons)(2000 lb/ton)(cy/500 lb) = 25 billion cy

The required area of the landfills of 6 ft lifts, 3 lifts high (total depth = 18 ft) equates to 4.1 billion sq yds or 850,000 acres or 1,300 square miles. This is slightly less than the land area covered by the state of Delaware.

This is a conservative estimate considering that 1994 statistics report a central Pennsylvania MSW manager serves 75,000 residents and 10,000 commercial customers. After recycling 50 tpd of recyclables from collected MSW, approximately 750 tpd of leftover wastes are deposited in the landfill.[8] So, 20 pounds per capita per day may be more realistic.

Recycling is a viable option that helps reduce the landfill requirement. In Japan, where land is scarce and recycling has long been culturally ingrained, currently only about 30 to 35 percent of household garbage is recycled.[9] An optimistic prediction is that the United States may at best achieve actual recycling of 30 percent in the future. If this goal were now being reached, 910 square miles of landfills would still be required to accommodate MSW for the next 30 years, an area comparable to the size of Rhode Island (1,045 square miles). One alternative beyond tolerance is mountain high MSW deposits like the Fresh Kills site on Staten Island. This MSW deposit site already covers over 2,200 acres.[10] By the time of its closure in the year 2005 the garbage will stand over five hundred feet tall and will loom larger than any other coastal landmark between Maine and Florida.[11] Dimensions as these prevent any attempts at daily covering and final encapsulation due to prohibitive costs for importing clays and dozer operations.

Effectiveness of Recycling:

As noted, Japan's stalwart, long-standing, well-organized recycling program has leveled at about 32 percent effectiveness. At best, in the next quarter century the fledgling recycling which has begun in the United States may reach 30 percent effectiveness. It is interesting that even with the current height of awareness for recycling, per capita waste generation is still rising which tends to partially offset waste reduction gains made through recycling. Programs for recycling rely heavily on behavior modification, morals, desire to participate, incentives, reinforcement and even enforcement. In suburbs and rural areas recycling is noticeably more successful than it is in inner cities. Several social reasons can be attributed to this occurrence, one of which is that in large apartment complexes it is quite difficult to enforce rules.

In Chapter Six it is shown that participants can quickly revert back to the bad habits of not recycling dependent upon certain events altering public sentiment. Many regions have recycling that is too complicated to work. Woodbury, New Jersey has some of the toughest recycling requirements in the nation, mandating separating trash into eleven receptacles-- for colored glass, clear glass, newspaper, mixed paper, cardboard, paper bags, dirty paper, tin cans, aluminum cans, plastic, and nonrecyclable garbage-- or risk a $500 fine.[12] Rules are not consistent as outlined by public works departments in different counties which adds to frustration of today's mobile Americans. Willingness to participate is challenged by inconvenience and ill-perceived lack of potential societal benefits.

Recycling followed through can be a great value added to resource conservation. Aluminum recycles efficiently in all respects. The same cannot necessarily be said for other materials. The problem remains what to do with all of the materials collected. In Seattle, collection is so far ahead of market development that officials worry about mounting volumes of stored recyclables. It can be argued that unless manufacturers and industry make use of these materials what has effectively been created are neatly stacked

above ground MSW landfills. The problem is that, other than aluminum, many other materials are more costly to process than regularly used virgin materials. Also, greater pollution is generated from extraction of recyclables versus using various virgin materials.[13]

Without a doubt, recycling is here to stay, has its place, and America will refine technologies for its use. A realistic understanding that recycling is at best only a fraction of sound MSW management is crucial.

Leachate

MSW in landfills extrude leachate harmful to both the environment and human health. Drinking-water wells exist within one mile of 46 percent of the country's landfills.[14] The costs of contending with this contamination nationwide is staggering.

Groundwater:

There is a high degree of difficulty in tracking and predicting future migration of leachate plumes. The effects of leachate contamination in groundwater have numerous characteristics which include in part the following: pH, specific conductance, dissolved oxygen, calcium, magnesium, sodium, potassium, iron, manganese, ammonia-nitrogen, carbonate, bicarbonate, sulfate, chloride, nitrate, hardness, total alkalinity, total dissolved solids, chemical oxygen demand, and total organic carbon.[15] Certainly these constituents, depending on concentration, ruin otherwise valuable groundwater sources.

Liners, collection and treatment:

Over the past decade, state legislation, and now federal Resource Conservation and Recovery Act (RCRA) regulations, promulgated in October 1991, have mandated liners and leachate control systems.[16] The liners are designed to keep leachate contained and keep rainwater out of landfills. One of the most highly rated state-of-the-art liners entails fifteen different types of layers stacked under the MSW. Most of the layers are of varying thicknesses of heavy geotextiles. Even with such an elaborate design, operators are directed to pick residential refuse clean of all sharp objects larger than 18 inches in length. Additionally, landfill spotters have to keep an eye out to get rid of anything else that compaction dozers might push through and rupture the liner.[17]

Systems of gravel backfill and 6" perforated high-density polyethylene (HDPE) pipe are used for leachate collection. For the few modern landfills that have been constructed in compliance with RCRA, the leachate is pumped from the collection pipes into concrete holding tanks and subsequently transferred to trucks for transportation to existing county wastewater treatment plants for processing. Newly-constructed landfills in the year 2000

will include on-site specific leachate treatment facilities. The total escalation costs, not limited to monetary, for 21st century style landfills can only be speculated.

Long-term groundwater monitoring:

The logic might seem to follow that with the exceptionally well designed landfills long-term monitoring of leachate contamination effecting the environment should not be required. This is not the case. Regardless of documented engineering efficiency RCRA still requires long term monitoring. Landfill design engineers were questioned as to whether they would give a 100% guarantee that leachate would not escape at some time within decades after construction. Although engineers stand confidently behind the merits of their design they will not offer such a guarantee.

In chronological order the first concern is installation. Of greatest emphasis is the seaming of the liner segments. Miles of these seams are required to be sealed by heat guns in an average size landfill. A poor seam, or rip during installation is the most likely way for a liner to fail. Thus, the manufacturer's guarantee on a liner is worthless. When a landfill does get a perfect liner installed the next concern is to ensure that dozer compaction does not result in punctures. Even if these two hurdles are overcome the unknown combined hazardous substances of leachate may eat through the liner. Household wastes such as the sulfuric acid in silver polish and the napthalene in drain cleaners are highly corrosive and can eat through the petroleum based liners. Laboratory experiments indicate that volatile organic chemicals (such as toluene and xylene) can eat through synthetic liners. Among future causes that are likely to damage liners are trees that will take root or gophers and woodchucks that will tunnel through them.

The security provided by liner systems can only be considered temporary. The durability of various sorts of liners (constructed from synthetic and clay materials) is unknown, but estimates indicate that all will eventually deteriorate in a range of ten to fifty years. Thus, the polluting impact of landfillling garbage is only delayed, not ended.[18] A small 16 acre landfill in Cape May, New Jersey with a liner has been capped. Now, 18 wells have been drilled to the aquifers, enabling them to routinely check possible contaminates for up to 30 years as required after closing.[19] Later in Section II trade-off costs in the benefit/cost ratio of such extensive long-term monitoring is evaluated against a proposed alternative. One question that has not been adequately addressed by the waste management industry to date is "What is the strategy if a leak is detected?". Finding and repairing the hole in bottom liners of a large landfill presents an entirely new engineering challenge.

Gases produced

After leachate contaminate, the largest technical problem in landfill management, is the control of gas emissions. The causes and characteristics of landfill gases emitted by

decaying MSW are readily definable. The daily operation of fleets of compaction dozers also contribute to the sum of harmful emissions. Today's requirement of long distance trucking of MSW to remote landfills adds to collective exhausts attributed to landfilling as well.

Air pollution and greenhouse effect:

Beginning over three decades ago air pollution mitigation has become embedded in the national agenda to reduce environmental harm and health hazards. In landfills, natural anaerobic (oxygen-deprived) decaying processes often convert benign waste into toxic chemicals which pollute the air. Most landfills in operation today lack a comprehensive gas-collection system. As a result, methane, carbon dioxide, and trace levels of carcinogenic-organic chemicals (such as vinyl chloride, toluene, and benzene) produced by decaying garbage escape directly into the air.

Gas emissions from landfills are a growing concern because methane traps about 25 times more infrared energy than does carbon dioxide, the trace gas most often cited as the leading contributor to the possible heat blanketing of the earth. Methane emissions from U.S. landfills alone contribute as much as two percent to the entire global buildup of greenhouse gases. By comparison, landfill-methane emissions, through their greenhouse effect, easily exceed the amount of carbon dioxide expelled by 10 million automobiles. Further clouding the landfill picture is that about 200,000 metric tons of volatile organic chemicals (V0Cs)--which can affect atmosphere ozone and smog concentrations--are emitted from U.S. landfills each year.[20]

Encapsulation:

Under RCRA Subtitle D New Source Performance Standards of the Clean Air Act encapsulation of newly designed or expanded landfills is now required. Not only does this control gas emissions, but also curbs transmission of disease by animals or insects. Diminished potential for the inadvertent starting of landfill fires is another benefit of encapsulation. Noting the primary objective of landfill encapsulation is to prevent unabated escape of harmful gases into the atmosphere, monitoring effectiveness remains a complex endeavor. For many of the same reasons cited for leaking leachate liners the same holds true for compromising the integrity of encapsulation.

Energy use of methane:

In some cases there is value in the harnessing of methane from landfills as an energy source. As expected, simple economics is the dominating factor that diswades the use of this energy source. Nationwide, about 1,500 landfills which incorporate at least partial encapsulation deal with gas emissions by venting or burning gas as it escapes from collection pipes. Industry continues to experiment with cost effective methods of collecting, purifying and transporting landfill-methane for productive use. One Los

Angeles-based Energy Company maintains that "Unless a landfill emits enough methane to produce two megawatts of power, we're not interested. It just doesn't pay out."[21]

SUMMARY

The problem with landfill management of MSW is that space in densely populated coastal zones is limited. Therefore, trucking MSW long distances is an expensive alternative. Once garbage has reached its ultimate destination the costs of dozer operations, labor, liners, encapsulation and long-term monitoring is extensive. As conservatively calculated 910 square miles of additional landfills will be placed in the next thirty years. Landfills can take as long as 90 years to complete their process of decomposition. Alarmingly this duration is prolonged by the removal of leachate which ordinarily facilitates biological decomposition. Assuming that a standard of 18 groundwater monitoring wells is required for each 16 acres, then 910 square miles of landfills will necessitate at least 670,000 monitoring wells. The wells would be tested for a full century. This is not practical. That is only half of the monitoring, because air quality is to be maintained too. The final dilemma is locating and accomplishing repairs for breaks detected.

CHAPTER TWO
ELECTRICAL GENERATION

An emerging major concern of Americans is the siting and subsequent safe operation of new power plants. The country is also becoming more educated about various environmental impacts and health risks connected to most of the existing power plants. The bulk of central station power is generated in one of three ways: from the burning of fossil fuel (coal, oil, natural gas), from the burnup of nuclear fuel, or from the force of water (hydroelectricity). The fuel mix for power plants in America varies depending on driving technologies and politics, but has held basically consistent for the past two decades. Total electricity generated in the USA is derived from 50% coal plants, 10% fuel oil plants, 13% natural gas plants, 17% nuclear power plants, and 10% hydroelectricity.[22] None of these approaches to generating electricity are without undesirable impacts.

Demand for electricity

Consumption of electricity in the USA continues to increase much the same as the continual increase in consumer goods consumption and increased MSW generation. Nationwide total electricity consumption over the past century has steadily grown at a rate greater than population growth. It is generally accepted that the United States population is growing at a 1.0 percent/year rate.[23] The annual growth rate of electricity consumption was 7.7 percent/year in the 1960s. After the massive conservation efforts of the 1970s and early 1980s the growth rate has settled out to a steady 2.0 percent/year.[24] This is still twice the rate of population growth.

Population increase:

Noting that projections are imperfect by nature, it can be expected that at a 1% annual rate the population of the USA will grow by 35% over the next thirty years. For the same thirty year period at a 2% annual rate the projected growth in electricity demand will increase by 81%. This means, at equivalent capacities, 810 more power plants will have to be constructed before the year 2025 to add to each 1,000 plants in place currently. Great resistance exists to stop even the replacement of the many plants that are already older than their useful service lives. The public will have to decide which types of power plants are best and where to site them. Another integrated plan is to use even less electricity and/or reduced population growth, including immigration. None of these suggestions are palatable to the majority of Americans.

Fossil fuel

Domestic coal in the United States and its territories that has been proven recoverable with current technology and economics amounts to 434 billion tons. At current power plant use rates of 814 million tons/year this coal can sustain the USA for 535 years.[25] The issues are that underground coal mining may be dangerous and unhealthy. Surface (strip) mining scars the landscape if done improperly. Coal mining also contaminates surface and subsurface water. Most recently it has been documented that coal mining operations result in significant undesirable subsurface hydrological changes. More alarming is the fact that these aquifer impacts can cause subsidence, a noticeable alteration of topography.[26] Air pollution is created by the equipment operations at the mine and by the rail movement of the coal. New intermediate complicated processes such as coal gasification or liquification are being researched. By-products of these processes further adversely effect the environment. Opponents state that burning coal at power plants produces not only carbon dioxide, but also particulates, sulfur oxides, and acid rain. The statement is a fact, but today's technology in practice prevents most of those emissions from reaching the atmosphere. Lastly, ash from coal burning must be disposed of. A 1000 MW plant burns about 12,000 tons of coal and generates 1000 tons of ash daily.

Domestic oil that has been proven recoverable with current technology and economics amounts to 40 billion Bbl. It is estimated that at current use rates this amount of oil would supply the USA for seven years. Clearly the United States is heavily dependent on foreign oil supplies. In 1993 oil imports to the United States reached a record 49.5% of consumption. While domestic oil production sank to a 35-year low, the American Petroleum Institute has said that this trend will continue because producers are banned from drilling in environmentally sensitive areas.[27] The security of oil continuing to be imported to the USA during any given era is questionable. The Arab Oil Embargo of 1973-1974 caused great concern and many utility providers operating fuel oil plants began converting back to coal use. In the wake of the Yom Kippur War, Middle Eastern oil producers cut off shipments to the United States and OPEC nations multiplied the price of oil several-fold. The Iraqi invasion of Kuwait in August 1990 also effected imported oil flow. For just such reasons the USA has created a Strategic Petroleum Reserve of 587 million barrels kept in places like the old void salt caverns near Houston. Environmentalists strongly oppose the transporting of oil in ocean tankers and the piping transfer of oil. Petroleum distillation plants are used to process crude oil into burnable grades for power plants and this processing discards byproducts possibly hurting the environment or presenting health risks. Once the fuel oil is burned at a power plant it too produces carbon dioxide and other air pollutants.

Of the four or five most relied upon energy sources for producing electricity natural gas, for good reason, is increasing in use to the greatest extent. Many utility companies are turning to natural gas in new plant design. Natural gas is considered to be

a clean, efficient burning fuel. A "clean" burning fuel does not mean that exhaust from burning natural gas is totally devoid from effecting the atmosphere. It is also becoming evident that natural gas is not an endless supply of energy just as has been learned about geothermal energy.

Up to 70 percent of the nation's fossil fuel plants are nearing retirement age.[28] It is probably not wise to commit the country to yet another generation of fossil fuel-fired electric plants. The problem in the designing and construction of new plants is choosing a long term dependable energy source. Coal has remained the dominant fuel for the entire history of the electric utility industry. Many utilities in the 1960s switched from coal to oil to avoid the environmental problem involved in burning coal. In the 1980s, many of the same utilities then switched from oil to coal to cut down dependence on foreign oil.

Nuclear

Beginning in the early 1960s the electric utility industry began to view nuclear power quite optimistically as what appeared to be an economical and benign source of energy. Development of nuclear power plants proceeded rapidly throughout the 1970s and 1980s. Today there are exactly 50 nuclear power plants in the United States of capacities greater than 1,000 MW.[29] Nuclear energy seems to have reached an apex of generating 17% of the nation's electricity. The outlook for the future that nuclear energy will play in the role of electricity production in America has changed considerably as the 21st century nears. Environmental opposition, stringent Nuclear Regulatory Commission (NRC) rules for construction and safety, and exceptionally high costs have brought the growth of nuclear power to a halt.

One of the reasons for the decline in continuing development of nuclear power plants is the public perception of more accidents such as those occurring at Three Mile Island and Chernobyl. Highly improbable events have a way of happening in complicated technological systems, as demonstrated by the sinking of the "unsinkable" Titanic, the 1965 Northeast power blackout, the space shuttle Challenger mishap and the failure of other "fail-safe" and "fool-proof" systems. A 1990 investigation by Congress' General Accounting Office (GAO) found that more than 60% of the nation's 107 nuclear power plants were either operating with substandard parts in their safety systems or had them in their inventories. The bogus parts problem is so widespread, the NRC may have to force numerous shutdowns to ensure that public health and safety are not at risk.[30] Next is the concern for safe uranium mining, extensive processing of U_3O_8 to UF_6 and transportation of frabricated fuel to reactor sites. The ultimate resting place of spent fuel at the end of the fuel cycle is the source of great debate. Potentially the spent fuel from nuclear power plants poses danger to the environment and health for thousands of years. The United States, nearly a half century into the nuclear age, has not adequately developed nuclear

waste storage facilities and seems years away from doing so. Spent fuel is a growing problem that could force the closure of nuclear power plants unable to find disposal facilities. The U.S. DOE's largest effort to date for a national permanent nuclear waste repository has spent $2 billion of a $6.3 billion total project budget. In six months, working five days a week and three shifts a day, the tunnel's 25-ft-dia boring machine has driven only 1,800 ft. The finished tunnel is to be a 5.5-mile loop. On 12APR95 the machine reached an anticipated fault zone. The tunnel collapsed and shoring was necessary to free the machine.[31] The British are facing the same problem. They are spending $190-million on a rock characterization laboratory that will be completed in the year 2005. After the lab is completed then construction will begin on 1.25 km of tunnels for storage located 800 m below the seabed off the coast of northwest England. The repository is scheduled to open for operation in the year 2010.

In the USA construction at the site of two different, partially completed, major nuclear power facilities has been abandoned. The Tennessee Valley Authority (TVA) will not complete construction on its partly built nuclear units because of prohibitively high costs. Construction on three units, one 1,170 MW and two 1,330 MW, will not be restarted. TVA still intends to complete construction next year on another 1,170 MW unit, which will now become the last nuclear unit under active construction in the U.S.[32] This is a strong indicator of the future considering that nuclear power plants have been under construction for many decades in the USA and increasing demands for electricity required continued expansion in the industry. The three halted TVA nuclear units have already cost $6.3 billion and would need an additional $8.8 billion to complete. The country's ambitious nuclear power program is coming to an end. The Washington Public Power Supply System has requested proposals to demolish what remains of four partly built units at Hanford and Satsop. The agency defaulted on $2.25 billion in bonds sold to partly finance units 4 and 5 when they were 20% complete. Work halted on those projects as well as the 1,240 MW units 1 and 3, both 65% completed. Only the 1,150 MW unit 2 went into operation, in late 1984. Two of the four incomplete units were gutted and abandoned in 1983. More than $10 million a year are spent to preserve the two remaining unfinished units and their licenses. It has been determined that the hundreds of millions of dollars required to restore the two units far outweighs benefits.[33]

One significant issue facing the nuclear power industry today is the problem of decommissioning plants after useful service life or other early permanent shutdowns. Fort St. Vrain Nuclear Generating Station is one of the first reactors to be decommissioned under the NRC's decommissioning rule. This small 330 MW plant began operation in 1979 and was permanently shut down in 1989. The decommissioning contract was awarded for a firm fixed price of $157,472,700 in 1990. Currently, physical dismantlement activities are about 45% complete.[34] It is difficult to defend the costs of nuclear power when examining a plant like this that took ten years to construct, had a ten year service period and will take ten years to demolish.

The problems with nuclear power plants are numerous and are not readily solvable. Environmental opposition, complex permitting, construction costs that are twice as expensive as conventional plants of equal capacity, radioactive waste management and disposal, and ultimately enormous decommissioning costs all severely hamper the practicality of generating electricity using nuclear fuel.

Hydroelectric

Generation of electricity through use of hydropower has reached maximum tolerable acceptance in America. It was believed in the first half of this century that hydropower would provide an abundance of electricity for generations to come. Boulder Dam, begun in 1928, was finished in 1936. Also the TVA and Bonneville Power Administration aggressively built dams on the Tennessee and Columbia River systems. By the 1940s hydroelectric power constituted 30% of the installed electric generating capacity in the USA. As of 1977 hydroelectric power had declined to 12.3% of the country's total generating capacity and today amounts to providing less than 10% of America's electricity.[35] Undoubtedly the percentage of electricity supplied by hydropower will continue to decrease as demands increase. Use of water power depends on availability of good hydropower dam sites. Most of the major sites have been utilized or are in congressionally protected park areas and/or protected by the Wild and Scenic Rivers Act of 1968. In today's environmentally sensitive era, few hydropower projects are even being proposed because they would face sure and stiff opposition.

The problems faced by any further expansion of hydroelectricity are fairly basic. There is no accessible untapped river power remaining to be exploited. Most of America's river systems are already being fully utilized. By 1977 there were about 50,000 dams in the United States. Approximately 1,400 of these are conventional hydroelectric plants. They have a total capacity of 65 million kilowatts and produce an average annual output of 287.8 billion kilowatt-hours.[36] The distribution of hydroelectric resources in the United States is highly regional with about 46% of the operating capacity in Washington, Oregon, and California.[37] One primary concern that has successfully stopped the development of any additional hydropower dams in the USA is the adverse effects dams cause to ecosystems. The most noted argument is the disruption or total elimination of important fish runs. A large preservation effort is underway from coast to coast to protect many types of fish runs. Not only does the preservation of fish stop the siting and construction of any new dams, but it has also heavily impacted existing dam operations.

The effects of the preservation campaign have sparked considerable innovativeness from engineers, caused the expenditure of millions of dollars and have reduced power production of the existing hydropower dams. The small 48 MW Racine

Hydro Plant on the Ohio River estimates exclusion screen costs at 12 to 60 million dollars to place and another $30 million for maintenance, lost energy, etc. The Conowingo Hydroelectric Station uses a "fish lift" designed to attract, collect and pass up to 750,000 American Shad and 5 million River Herring upstream of the dam each spring. Construction costs for the lift were $10.5 million in 1991. Other systems such as large hydrophones and electric pulse are also used to modify fish migration.[38] The Hungry Horse Dam in Montana is faced with a real problem because the turbines are 241 ft below the pool level which makes discharges extremely cold. Shock caused by the water release through the power house has reduced bull trout populations below the dam.[39] Several of the primary salmon populations in the Columbia River Basin have drastically declined and are now protected under the Endangered Species Act. The Columbia & Snake River System has 20 major dams and 100 other smaller dams to produce power. Legislation was enacted in 1980 to give salmon coequal status with power. On the Columbia River, baby salmon are dependent upon the flow of the river to carry them out to the ocean. The static holding of water in reservoirs detain the juvenile salmon's ride and cause death. Those that might make it are chewed up in turbines. "Fish barging" the fish downstream over a period of 17 years has proven ineffective. The governor of Idaho has proposed a 3/4 billion construction modification project to modify dams to enhance salmon survival. The Bonniville Power Administration is fighting the plan, but has a plan of its own to comply with the 1980 legislation. The power company's solution is to increase the water flow not passing through turbines. The utility board members voted 6 to 8 to <u>open</u> the flow of the dams such that dams will no longer be operated to maximize power production. This will create a $177 million per year loss of electricity revenues and will also result in a $2 or $3 monthly rate increase for each resident.

Canadians are also turning away from future hydroelectric production as a result of great losses involved with failed projects. In 1993 British Columbia's government axed the partially completed $920-million project to increase hydroelectric production by 540 MW at its Kemano project. The project would have seriously threatened a major salmon run.[40] The biggest hit to their hydropower future was the cancellation a $10 billion hydropower project on the Great Whale River after having already spent $200 million in planning. Native Americans were instrumental in showing that the 5,000 page environmental impact statement was unable to project real costs and benefits. Three dams for the 3,212 MW powerhouses would have flooded 600 sq miles of pristine wilderness.[41]

Hydropower should not be relied upon to solve the increased future demands for electricity. Land resource changes that occur when a reservoir of water is created have become unacceptable to the masses. There are no more sites available in America that the public is willing to dedicate for this use. Existing capacities are being curtailed in the interest of environmental enhancement, namely fish runs. Today's water resource managers continually balance the competing needs for the energy head available in reservoirs for uses other than electrical generation. Gravity fed distribution pipes that are

supplying increasing city water demands use much of the energy head directly from reservoirs above dams.

Alternative electrical generation

As demonstrated by increasing topic dominance at the Annual American Power Conference a wide array of alternative energy sources are being researched to produce electricity. All solutions for means of generating electricity have some drawbacks. Solar radiation intensity varies with seasons and collection fields require large land areas. Solar energy sources also operate at low efficiencies such that even though the fuel is free capital investment for collection, storage, and transformation of energy is high. Ocean thermal gradients provide useful energy from a $38^{o}F$ variant from ocean surface to a short depth of 3,200 ft. After extensive research, no cost effective means has resulted for generating electricity from ocean thermal gradients. Wind energy harnessed for generating electricity parallels some of the same problems faced by solar energy. Tidal energy is site specific and is certain to be opposed for coastal ecosystem concerns. Geothermal energy use to produce electricity has been extensively developed and has proved limited in value. Most geothermal wells do not produce steam, but rather brackish, corrosive hot water. Many of the better geothermal locations are in rocky mountains zones in parks or, at the least, impractical to develop. Some geothermal sites are being explored with difficulty as deep as 30,000 ft below the Gulf of Mexico. Seawater hydrogen and many other sources of energy are being researched with no great success stories for generating electricity.

SUMMARY

The electric utility industry certainly has challenging problems to contend with in order to continue to meet demands. Coal has remained the dominant fuel for the entire history of the industry. The real beginnings of a permanent shift away from coal are happening because of its inherent environmental adverse impacts. Nuclear power plants cost more than twice that of conventional plants for construction per MW capacity and at least quadruple the relative costs of conventional thermal plants for decommissioning. The solutions and costs of radioactive waste management and disposal have yet to be defined. Sustained supplies of natural gas remain unproven. As for fuel oil plants, the annual U.S. demand for electricity is expected to double over the next thirty years and worldwide electricity demands are projected to triple for the same period. Knowing that America is highly dependent on foreign oil imports, the conclusion is drawn that

competitiveness for world oil resources will stiffen. Dr. Chauncey Starr, a member of a number of energy-related groups provides concisely the present and future challenges:

"The projected electricity demand increases will tax man's ability to discover, extract and refine fuels in the huge volumes necessary, to ship them safely, to find suitable locations for several hundred new electric-power stations in the U.S. and to dispose of effluents and waste products with minimum harm to himself and his environment. When one considers how difficult it is to extract coal without jeopardizing lives or scaring the surface of the earth, to ship and transfer oil without spillage, to find acceptable sites for power plants and to control effluents of our present fuel-burning machines, future electricity demands indicate the need for thorough assessment of the available practical options and careful planning for our future course."[4]

CHAPTER THREE
FRESH WATER AVAILABILITY

Human life cannot be sustained in the absence of fresh water to drink. There is a finite amount of water on earth of which no additional volume will be created and no volume will be destroyed. The problem is that as human populations continue to increase worldwide demands on limited fresh water intensify. Distribution of all water on the planet is depicted in Figure 3.1.

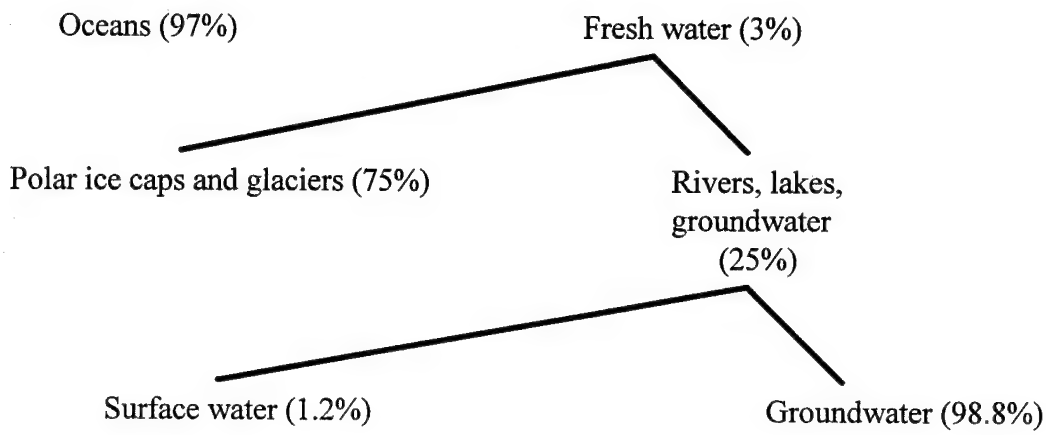


Figure 3.1 Distribution of water on earth (From Wolman, 1962.)

The percentages of surface water and groundwater simply quantify volume. Availability of this fresh water for use by humans is much less than the percentages shown in Figure 3.1. Much of the groundwater is located far from points of need, or at depths and in aquifer materials that make retrieval impossible or uneconomic. In the United States the physical limit of fresh water supply, calculated as annual precipitation runoff, is 1,200 billion gallons per day. The Geological Survey estimates that if groundwater recharge was mechanically increased significantly, extensive conservation measures were conducted, and evaporation is reduced, the maximum economically dependable supply is about 500 billion gallons per day. The total consumption in the United States presently is about 120 billion gallons per day and this figure increases by one billion gallons each year.[43] It seems that Americans have ample water supply for the next few centuries, but this is not the case. Nonconsumptive uses like navigation, hydropower, recreation and wildlife habitat hold as much as half of America's fresh water sources in a status that prohibits withdrawal. Further difficulties are due to the variability of geology, climate, landforms, and the distribution of population and industry whose requirements do not match water availabilities. Today, 49 of the 50 United States excluding Alaska are struggling with the management of limited fresh water supplies and increasingly competitive demand requirements.

Surface water

There are very few projects being proposed for further withdrawals from surface waters in America. Between the Rocky Mountain Range and the Mississippi River there is not one river remaining that flows naturally. Every river is regulated with diversion dams, reservoirs or massive pumping. Water resource managers throughout the United States are contending with overwhelming demands that compete for the use of surface water. Recreationalists above dams prefer that greater amounts of water be retained. Recreationalists below dams want more water released. In almost all situations, various river habitat in the water and on land both above a proposed dam and below a proposed dam would be harmed by the placement of a new dam. Many dams establish a reservoir for multipurposes. The energy head of reservoir water is used to turn turbine generators, but city waterworks departments rely on this same energy head as the driving force in gravity fed transmission water pipes to supply municipal water. As electricity and potable water demands continue to increase along with population growth many reservoirs are no longer adequate to fulfill both consumptive and nonconsumptive needs.

Sediment abnormalities are being created above and below dams throughout the country. Above the dams, build up of sediment in the slow moving reservoir pool is decreasing water storage capacities. Below the dams, less sediment in water facilitates the acceleration of erosion. Most dams also have narrowly defined operating rules used to mitigate flood damage. Reservoir pools are maintained at levels lower than maximum capacity so that flood waters can be held back and then slowly released. Larger volumes of water could be stored for municipal use, but then property and crops are at risk due to substantial damage when the twenty year excessive rain occurs. Also, if water is pumped at faster rates from rivers and lakes, the navigable waters which support much of the nation's economy will become too shallow.[44]

Sewage treatment plants across America discharge secondary effluent into rivers where dilution and the natural aerobic process integrates human waste safely back into the environment. As civilization continues to inhabit more land along rivers downstream of sewage plants and as sewage volumes increase, human waste products are showing up in municipal water. New York City, long boasting of water called "champagne out of the tap," is now having to filter its supply from upstate rivers contaminated by sewage plant discharges.[45]

The Great Lakes represent about 20 percent of the world's and 95 percent of the United States' surface fresh water supply.[46] 40 million people including one-third of the population of Canada live in the Great Lakes Basin and depend on its fresh water. Millions fish, boat, and swim in the waters of the Great Lakes. The lake system provides a water transportation route from the Atlantic Ocean to the heart of North America. Hydroelectric power is generated by the elevation differences found along the lakes and numerous power plants draw cooling waters from the lakes. Needs and uses for the Great

Lakes water have become intensely complex and are very sensitive to changing levels of the lakes and the amount of water available at any given time. Because populations are still growing around the lakes, the region is now faced with the beginnings of inadequate water supplies for agriculture, power, human, industrial, and transportation needs. Major diversions of the Great Lakes waters are being sought to solve other needs for water in the Illinois River system and the enormous Ogallala aquifer depletion problem. Without a doubt, there will be immediate severe adverse impacts in the basin if either of these two proposals are approved.[47]

Throughout the country similar water conflicts and shortages are common. The purposes of dams inevitably are added to long after original planning and construction. The Norfolk and Bull Shoals Dams on the White River in Arkansas were constructed in the 1950s for flood control and hydropower generation. Decades later water supply was added to the list of purposes and, more recently, recreation, fish, and wildlife have been added as purposes for the dams. Conflicts between upstream and downstream demands on the dams continue to intensify.[48] Major investments have been made at ports along 445 miles of the McClellan-Kerr Arkansas River Navigation System which connects with the Mississippi River. Navigation along this waterway is now being threatened by consumptive use withdrawals.[49] In Nebraska the Box Butte Reservoir has suffered chronically low water levels from drawdown to meet irrigation needs, i.e., losses to fishery and recreation have been significant. No state has been saved from escalating water use. For the first time, water been siphoned from the McClusky Canal in North Dakota to several adjacent wetlands to help sustain breeding habitat for waterfowl.[50] Virginia and North Carolina have just concluded 11 years of litigation which will allow Virginia Beach to place a 76-mile pipe for drawing the last available 60 mgd from Lake Gaston.

The Colorado River stopped reaching the ocean many years ago because of dams and large volumes of pumping for consumptive use. Native Americans, recreationalists, agriculture, power generation, urban growth, hotels, casinos, and others place demands on its water. Farmers who had never questioned the adequacy of Colorado River water for livestock became locked into battles with Las Vegas and the Lower Colorado River Authority of arid southwestern states for water use. Las Vegas has a very high per capita water use of 310 gpd, a scanty rainfall of 4 inches annually and a rapid population growth of 8% annually that adds 1,500 new residents weekly to the current 1 million inhabitants. The first of several billions of dollars of water supply projects planned by Las Vegas is a $175 million second 4-mile tunnel to Lake Mead. This project alone will supply an additional 80 mgd to Las Vegas and result in withdrawing another 80 mgd directly from the Colorado River. Alarmingly, the added 80 mgd, which will boost municipal supply to Las Vegas to 480 mgd, will only suffice to satisfy requirements for two more years at the present growth rate.[51] The "Colorado Ute Indian Water Rights Settlement Act of 1988" is one of the latest blows which clearly has demonstrated that there is insufficient water supply from the Colorado River to satisfy the known legitimate requirements. The Ute

Indians occupy considerable land on the northern portions of the Colorado River and are now aggresively exercising their claim to Colorado River water use.[52]

The population of California is expected to grow from its present 32 million to 49 million by 2020. No new water projects have been built for the past 24 years.[53] Water rationing has become a common event, farmers are limiting crop production and wildlife is suffering. Every year the legal water battles over severely limited resources become more entangled. Northern California has permitted much of its surface water supply to be channeled to the drier and heavily populated Southern California region since the 1960s. There are few development areas remaining in Southern California that can satisfy municipal water requirements solely from local water resources. A multitude of places such as the Goleta Valley and Santa Barbara are highly desirable locations to live and ironically also have the most inadequate local water resources. The effects of water conveyance are being felt heavily in Northern California especially as the upper half of the state continues to grow in population. Lake Shasta, Lake Pyramid, Mono Lake and others are experiencing lower levels every year.

Riverside County, California is proceeding with plans to construct the Domenigoni Valley Reservoir for a cost of $1.97-billion. It will include three earth and rock dams: a 1.7-mile long, 285-ft tall dam, a 2-mile-long, 185-ft tall dam, and a saddle dam.[54] To fill the Domenigoni Valley Reservoir and treat water a $750-million major water line and treatment plant will have to be financed and constructed. The water line would deliver water from Lake Mathews, the terminal reservoir of the Colorado River aqueduct. The water line will require placement of an 8-mile tunnel over 2,200 ft beneath the Santa Ana Mountains. Amazingly this nearly $3 billion project continues to move forward in the face of definite uncertainty about future water availability from the Colorado River for Southern California.[55] Also, San Diego is proposing a half a billion dollar project to provide additional fresh water storage.[56]

Texas is primarily dependent on groundwater, but exploits its surface water resources as well. Possum King Lake on the Brazos River in Texas is a 570,000 acre-foot reservoir which is heavily depended on for water supply in Palo Pinto County. The U.S. Fish and Wildlife Service successfully intervened when the Federal Energy Regulatory Commission applied for its license renewal in 1985. As a result of restrictions placed on the new license water supply, hydroelectric generation, and recreation have been curtailed.[57]

Even the seemingly wettest states are running short of fresh water to supply their minimum demands. The Cedar River basin in Western Washington has experienced an increasingly competitive demand for water to support municipal and industrial use and a valuable fishery. The listing of the Columbia and Snake River Sockeye Salmon as endangered species has abruptly limited municipal and industrial water supply appropriations from these two primary rivers. It is more than evident in the United States that surface water, a small 1.2% of all fresh water, is being overtaxed and has little if any additional capacity to provide.

Groundwater

About half of the fresh water consumed daily in the U.S. is supplied from groundwater sources. More than 90 percent of rural America is dependent solely on groundwater for survival. Fiftyfive percent of water consumed by livestock and 40 percent of water used for agriculture is supplied from groundwater withdrawal. Roughly 73 percent of all groundwater pumped is used for agriculture irrigation.[58] Advanced groundwater pumping technologies and increasing demands for water have placed almost every aquifer in the country in a status of overdrafting. On average, groundwater is being extracted in all locations at a rate twice that of natural recharge capacity. Thousands of wells are drying up and leaving communities with only rainfall to supply future water.

The most noted groundwater crisis is the depletion of the Ogallala aquifer that underlies eight states in the center of America. This aquifer, the largest in the U.S., was formed during the Ice Age and required centuries to reach its saturated volume of a quadrillion gallons. In 1950 extensive pumping of the Ogallala aquifer began and the supply was believed to be unlimited. As early as 1960 it was realized that the source was not infinite. There has been a 110 to 120 ft water well level drop caused by the past forty years of pumping. Since the advent of "center pivot sprinklers" that have dominated the high plains for the past few decades, the aquifer is being used up 25 times as fast as it is being replenished. At the current use rate, in the next forty years there will be a total loss of irrigation ability. Thus, dry land farming will again become the standard new mode of operation. In many cases farmers have already reverted back to dry land farming.[59] This takes 4 times as much land to produce the same quantity of produce as from an irrigated field and is highly susceptible to drought devastation. Without Ogallala groundwater, all cattle dependent upon it in the eight states will have to cease to exist. Kansas won a Supreme Court decision to establish the first "Intensive Groundwater Use Control Area".[60]

In the state of Florida 90 percent of the drinking water comes from aquifers.[61] The current population of Southern Florida has exhausted groundwater capacity to supply municipal requirements. Development of sinkholes, caused by over pumping, is a regular occurrence. Ironically, populated areas like Southern Florida that are in the greatest need to recharge aquifers, cover much of the land with concrete or asphalt and efficiently divert storm water in a way that prevents percolation. Citizens of Tampa Bay are proposing that a state water board be formed. This would permit consensus votes from the heavily populated southern cities to approve a 250-mile pipeline transfer of groundwater from the citrus growing northern counties.[62] This pipeline project, less litigation, will cost about $350 million to build and $250 million annually to maintain and operate.

Tucson, Arizona and San Antonio, Texas were the last remaining major cities totally dependent on local groundwater. Both cities have reached a point where groundwater resources are inadequate to meet demands. Tucson has 196 wells at depths

of 50 to 400 feet. In the 1980s it became apparent that no more wells could be added and the water supply was running low for the city. In 1991 Tucson exercised its court-awarded right and began receiving 135 mgd of imported water from the over-burdened Colorado River.[63] San Antonio is proposing, for the first time, a surface water reservoir to supplement groundwater from the Edwards Aquifer.

Countries around the world have watched buildings sink because of geological subsidence caused by overdrafting aquifers. Mexico City has certainly experienced increasingly difficult problems with subsidence. Mexico withdraws 800 million m^3 annually from its main aquifer which has a natural recharge rate of only 300 million m^3 annually. The level of the aquifer is dropping 6 m per year.[64] For years Houston has been experiencing the same problem and closely monitors as much as two feet of subsidence of city topography known to be a direct result of aquifer depletion.[65]

Knowing that there a very few opportunities for future surface water development the states of California, Massachusetts, and others have implemented statewide stringent registration requirements for <u>all</u> groundwater wells. Limits on withdrawals are set for each well and the state meters all operations. Other states like Texas, where groundwater supplies approximately half of the annual water use, can't impose regulation because common law for groundwater applies. The English rule reads that a property owner has unlimited rights to pump underlying water at any rate for any purpose. The high plains of Texas which rely on the Ogallala aquifer have been experiencing severe water shortages every year because the English rule has allowed Texans to overpump and deplete the aquifer.

Clearly, the country is reaching the limit of maximum available groundwater abstractions. It will not be far into the 21st century when the United States has means in place to pump groundwater from every last practical aquifer source similar to the present use of surface water. Numerous cities have begun reaching out to great distances for the acquisition of additional groundwater. Las Vegas is planning to spend $2 billion dollars to pipe groundwater from as far as 300 miles away in order to tap some of the last obtainable water resource.

<u>Interrelated supply failures</u>

Systems that supply various needs of Americans rarely can be over used without adversely affecting other separate systems. Capacities of surface water and groundwater are often directly related. In the natural state, aquifers input about 30 percent of all river water flows.[66] In other locations surface water from rivers assist the recharging of groundwater. The residents of upper Florida have seen over pumping of groundwater dry up rivers and lakes. The only everglades in the world are in Florida. Originally the everglades had 4,000 sq mi of which over 2,000 sq mi have disappeared in part due to

groundwater pumping for sugar crops, citrus, urban growth and other reasons. The ecosystem is in collapse and a massive restoration program has begun to restore some of the lost water. Low river levels across the country have been attributed to extensive pumping of adjacent groundwater.

For both surface water and groundwater there is a natural barrier between fresh water and saltwater systems. Coastal states such as New York are now attempting to develop subsurface seawater intrusion barriers to protect depleted aquifers. Lakes in coastal states must maintain levels equal to the ocean or risk saltwater intrusion. Navigation locks can only overcome slight differentials in levels and seawater gets through when the level of a lake is low. Steady fresh water flow into estuaries and bays along the Gulf Coast and California is essential to the survivabilty of fragile ecosystems.

As municipal water demands continue to escalate, hydropower electricity supplied, critical navigable waters, water for crops and livestock, and adequate river reaches for treated sewage outfalls will all face regular failures.

SUMMARY

The most pressing infrastructure crisis in America is the supply of fresh water. In many areas of the country, there is little or no margin of reserve between supply and demand. This situation has created water shortages that are becoming the norm, rather than the exception as populations continue to grow. The vast majority of water resources available have been developed and are being fully utilized. In the interest of protecting land, vegetation, fish and wildlife, the retaining of reservoir water behind existing dams in every state is actually being altered to the detriment of municipal and industrial users.

The legal battles for water appropriation rights from Canada and Mexico, among the individual states, county to county, city to city, between land owners and different interest groups intensify with each passing year. To guard against shortages in the future, Tacoma will not even entertain the benefits of conjunctive water use with Seattle. Tucson, Southern California and Las Vegas are each proceeding with huge projects to withdraw even more water from the grossly over used Colorado River. These three are also simultaneously advancing projects at distances of hundreds of miles to get groundwater.

Naturally available fresh water resources in the United States are being used very closely to the fullest extent. If all of the fresh water feasibly obtainable in the 48 contiguous states were used only for municipal and industrial consumption there may be an adequate supply for the next fifty years. The problem is that severely adverse impacts would result to fish, navigation, hydropower, recreation, cooling water for power plants, agriculture, man-made snow, subsidence of topography and many other water dependent entities.

SECTION II
"The Solution"

CHAPTER FOUR
THE PROPOSED INTEGRATED FACILITY

Public Works Departments are faced with increasingly complex challenges that are no longer separable. Operation of a state-of-the-art, combined facility that disposes of MSW, contributes to electricity production and adds to fresh water availability is possible and practical. MSW can be reduced by 95% volume when used in the facility as fuel. The MSW provides a heat value, on average, of 4,500 Btu/lb and can be used to generate steam. The energy in the steam is transformed, in a back pressure turbine-generator, into electricity for consumption by local communities. Waste-heat recovery is a primary criterion. After passing through the turbine the steam still carries ample heat energy for use in a desalination process. In desalination, seawater is evaporated and the vapor produced is then condensed which provides fresh water.

This approach of increasing efficient energy use by the sequential production of electric power and useful thermal energy from a single fuel source is termed cogeneration. The efficiency of energy recovery is nearly doubled from the typical 35 percent at a conventional electric utility, to the 70 percent of this cogeneration facility. Without use of cogeneration most of the energy still available in steam after leaving turbines is completely wasted when heat is rejected from condensers. The only real opposition to implementing this facility is the perception that it will discourage recycling of MSW and that stack emissions from the furnace are harmful to the environment. In fact, recycling complements this facility because the removal of recyclables from MSW actually increases the Btu heat value in MSW. Also, by using up-to-date technologies, this integrated facility is the most environmentally responsible of all means available to Public Works Departments and is cost effective. The New Source Performance Standards issued by the Environmental Protection Agency (EPA) and Title V permitting are measures that help keep stack gas emissions to a minimum in conforming with the national agenda.

The trend and likelihood of this facility

It is clear that as long as the population of the USA continues to increase so will the daily volume of MSW generated. There is absolutely no indication that the population or MSW will not continue to increase in the foreseeable future. In fact, from 1980 to 1990, although recycling rates increased by over 40%, the amount of waste remaining after recycling grew by over 25 million tons per year. The population growth rate is holding steady at 1% while trash generation rates in the United States are showing an increase of 4.5% per year.[67] Even with this knowledge federal and state mandates require that the amount of MSW being placed in landfills must be reduced by 25% no later than the year 2000. There are essentially four methods to meeting MSW management challenges. They are, in EPA order of preference, source reduction, recycling, incineration, and landfills.

Source reduction has its practical limits. Economically source reduction is a detriment. In the process of minimizing packaging spoilage of perishables is prevented less, damage to consumer goods becomes more frequent, and overall safety and health is compromised. Spoilage of food in commerce in the United States is 17%, in the Soviet Union is 50%, and in India is 70%.[68] Yes, solid waste is important, but so is breakage, spoilage, safety, sanitation, and consumer cost. Public tolerance of the prices to pay for source reduction will place a limit on the usefulness of this practice. Recycling MSW is a sensible way to help decrease some of the amount of garbage which will be placed in landfills. The Public Works economics of recycling is questionable. This cost is passed on to consumers. Unless the playing field is assured to be even for the use of recyclables then American manufactures will competitively lose revenues to Mexico and Canada under NAFTA. Glass, aluminum and ferrous metals lend themselves to efficient recycling, but plastic does not recycle well. The most effective, time proven, recycling programs in the world all limit at about 30% less MSW which must be disposed of. This leaves a 70% requirement for alternative means of MSW disposal. For the 70% remaining many advocate incineration as the most environmentally responsible means of disposal. At the bottom of the EPA Office of Solid Waste hierarchy for MSW disposal is landfilling. Tipping fees are increasing at a rate greater than inflation. Complex, expensive liners and encapsulation are required by law. Long-term monitoring of all landfills place an additional burden on the nation's annual budget. Real estate on top of closed landfills is less valuable because of potential necessary repairs to the cells in the future. Lastly, in dense coastal populations far more economically productive uses are sought for valuable land space instead of landfills and the Senate has restricted out-of-state transportation of municipal waste. This is significant considering that 10% of the nation's total MSW is shipped from the heavily populated states to the less populated states. Congress has found the "alternatives to existing methods of land disposal must be developed since many of the cities in the U.S. will be running out of suitable MSW disposal sites within five years unless immediate action is taken."[69]

Electrical demand is growing, and the nation's generating capacity is failing to keep pace. Strong indications are that no more nuclear power plants will be placed in operation in the USA. The number of registered professional engineers paid on staff to license, maintain, and operate a nuclear power plant is very much disproportionately high compared non-nuclear power plants. High operating costs relative to other sources of electricity and an unresolved nuclear waste problem are the two major reasons for eventual elimination of the nuclear power industry in America.[70] Furthermore, the lead time needed to place a nuclear plant in an operational status is fifteen years on average. Many nuclear power plants are being decommissioned well prior to the end of their service life because of prohibitively high operating costs. Following this trend 17% of the electricity production capacity in the country today is destine to be lost. Capacity of hydroelectricity is also being reduced rather than increased. Oregon alone has lost 900 MW of hydropower from measures to protect endangered fish.[71] Declining hydropower availability will account for another 2% of lost electricity production in America. The nation's capacity to produce electricity is heading toward a 19% reduction. This is a problem in need of a solution.

Conflicting priorities for water use are mounting. It is well publicized that water supply has reached its limit, but people don't seem to be able to live without washing cars, using dishwashers, using clothes washing machines and taking water intensive showers vs. baths. Ironically, even recycling glass requires bottles to rinsed at home. Prior to mandating that water usage be curtailed most municipalities will increase unit prices of water hoping that the effect of price/demand elasticity will decrease demand.[72] More often the result is that politicians get voted out of office as a result. Opponents to the development of new reservoirs are fighting vigorously. In Colorado the proposed Two Forks Reservoir project has been canceled after having spent $40 million to draft an Environmental Impact Statement (EIS). Participants in the EIS inventoried and tagged just about every frog, bird, fish, butterfly, deer, invertebrate, kayaker, fishperson, relic, rock and fault line in the region.[73] Coastal states most in need of increasing water supply and unable to look inland for sources are using or planning for desalination. In June, 1995 Florida hastily approved spending $2 million of the state's budget for desalination planning. The production from desalination facilities remains constant and unaffected by weather. Such an insurance is very attractive to cities like Dallas, Texas which barely endured the most drastic emergency water measures on record in America during the North Central Texas drought of the 1950s. At some future date when water shortages are severe enough to cause great sacrifice in the quality of human life desalination will be widely used in the USA.

Middle Eastern countries are heavily dependent on desalination to sustain population growth. Of the whole Middle East region, Lebanon is the only country remaining that has not been forced to implement desalination.[74] Turkey is not only faced with inadequate water supply, but is also looking for answers to its MSW disposal problem.[75] Asia, The Philippines, Canada and Hawaii have turned to MSW combustors as a means to disposes of MSW and create electricity. Many small Pacific islands which are

densely populated use waste-to-energy (WTE) facilities and also use a separate facility for desalination to provide fresh water. Puerto Rico has recently entered into a contract for construction of a combined-cycle facility to generate electricity and 4 mgd of potable water for the island's south coast.[76] Waste-to-Energy facilities are certain to be a big piece of America's future, and environmentalists --- at least mainstream environmentalists --- seem more-or-less resigned to these plants as the only conceivable alternative to continuing reliance on landfills, many of which are old and not located in safe places.

The time has arrived where city departments responsible for MSW disposal, electricity supply, and water works cannot ignore each other while independently searching for and evaluating alternatives. Coupled alternatives is an emerging engineering issue in public works master planning. Cities that understand concurrent planning have already found the value of synergy and tied MSW disposal to electricity production. Other regions in America out of necessity have invested in electricity power plants that are tied to desalination. Seattle's Public Works policy is to integrate the management of all resources to ensure protection of all and to produce the best combination of benefits. Portland, Oregon and other cities have adopted the same policy. When and if the primary public fears associated with MSW combustors subside the facility introduced in this thesis, which interties all three utility infrastructure needs, can be put in use to benefit the USA.

Landfills and the development of incineration:

All forms of MSW management have some measurable degree of adverse effects. Incineration is the best way to dispose of trash that the public expects to have picked up at the curb twice a week. Most people now agree that landfilling is the most undesirable. The demarcation line that highlights the end of America's era of landfills is the realization that New York's Fresh Kills site is by far the largest landfill (or mound) in the world. The heightened awareness of the numerous unmanageable large USA landfills and concerns for the environment have resulted in the closing of 64% the nations landfills since 1978.[77] 8 out of every 9 landfills remaining in operation today are scheduled to close by the year 2000 and are face with enormous closing costs. Furthermore, almost no additional landfills are being proposed because it is very difficult to site and place into operation any new landfills.

Matter cannot be created or destroyed. Incineration is just a faster reducing medium than landfill decay is. Other environmentally conscious countries have worked hard make the most of recycling and still incinerate large percentages of MSW. Most European countries have as their official position that landfilling waste poses greater threats to the environment than do modern incineration practices. After considering all benefits and costs they have concluded that incineration is and will remain the best primary means of MSW disposal. Their view is that any electricity that may be produced by incinerators is just one more added benefit. All of the countries that heavily rely on

incineration generate considerably less garbage per capita than the U.S. does. (see table 4.1)

Table 4.1 Annual Waste Generation in Various Countries[78]

Country	Amount (pounds per capita)
United States	1920
Canada	1389
Finland	1120
Norway	1051
Denmark	1042
Luxembourg	1036
The Netherlands	1033
Switzerland	942
Japan	876
United Kingdom	793
Austria	789
Turkey	784
Belgium	776
Spain	716
West Germany	707
Sweden	704
Greece	698
Ireland	691
France	673
Italy	669
Portugal	513

Currently, incineration accounts for 70 percent of MSW disposal in Denmark, 40 percent in the Netherlands, 75 percent in Switzerland, 60 percent in Japan, 34 percent in Germany, 55 percent in Sweden, and 36 percent in France. Government officials in all of these European states intend to increase reliance on incineration. Some European countries already treat as much as 90% of their waste stream via combustion.[79] Japan's is now working on a ten-year plan to increase incineration to 70% and eliminate all landfilling. Recycling complements incineration by actually increasing the heat value for MSW and decreasing pollutants from incineration. Japan recycles 30%, incinerates 60%, and landfills 10%; Europe recycles 10%, incinerates 45%, and landfills 45%; and the United States recycles 16%, incinerates 14%, and landfills 70%. Norway believes that it does not have excessive garbage generated per capita, its recycling is effective and it is

not really limited for landfilling space. In Norway incineration is used extensively because they believe in addition to being an environment hazard, MSW landfilling does little to use garbage effectively as a source of fuel.

The U.S. will have permanently closed the vast majority of its existing landfills by the year 2000 and under strict new environmental standards few new landfills will be opened in the 21st century. This reality along with an understanding of demonstrated recycling limits leads to the conclusion that most of America's MSW will be disposed of by combustion for generations to come. The trend of increasing disposal of MSW by incineration in the USA is evident as seen in figure 4.1.

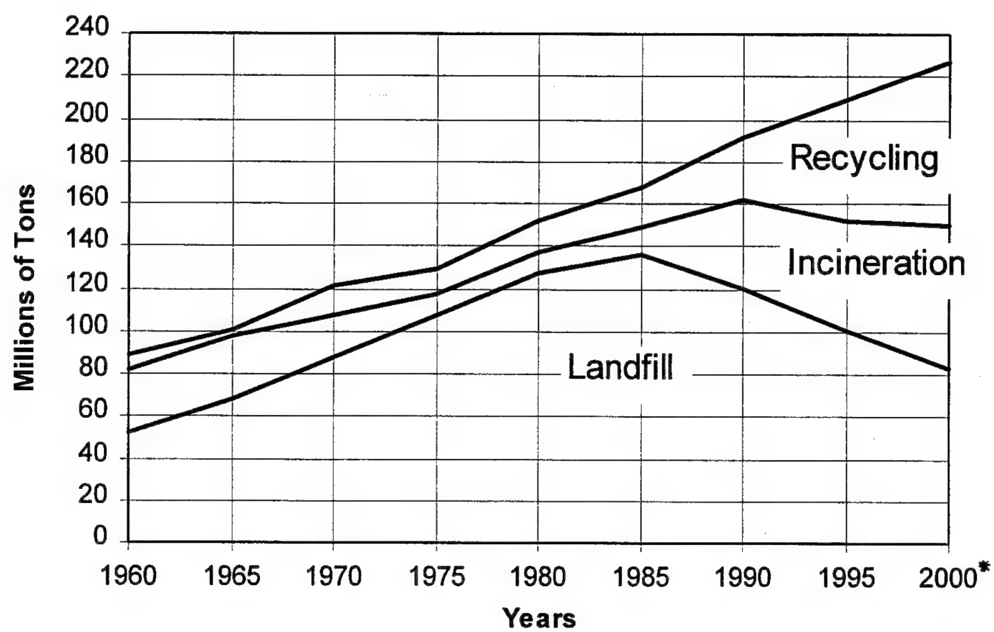


Figure 4.1 Municipal Solid Waste Management[80] (*estimated)

The first incinerator in the U.S. was designed and constructed in 1885 on Governor's Island in New York City. Of the 180 incinerators built in the United States between 1885 and 1908, 102 had ceased to operate by 1909.[81] The need for incineration returned and by the start of World War II some 700 cities had incinerators in operation. In 1960, 31 percent of America's MSW was incinerated. Twenty-eight years later, the share of garbage consigned to combustion had declined to 7 percent. This large reduction was due mostly to sentiment in the decade from 1975 to 1985 when environmentalism in America experienced great momentum. It was during this period that MSW combustors were portrayed to be toxic nightmares. The tide has begun to turn where more incinerators are now employed to dispose of MSW. Use of MSW combustion in the U.S. has certainly been inconsistent, but an appreciation of the value of incineration now appears to be here to stay. By 1991, the nation was back to burning around 14 percent of its MSW. Current state-of-the-art incinerator technologies can comfortably meet the

present air pollution control regulations. The EPA's Office of Solid Waste is an advocate of MSW incineration and has set a goal for 25% of America's garbage to be incinerated by the year 2000 and promotes increasing the percentage thereafter.[82] All indicators confirm that the EPA's intention is being followed. In 1985, 83% of America's MSW stream was landfilled and this percentage had dropped to 62% by 1993.[83]

Energy sources for electricity production:

The capacity to produce electricity in the U.S. must be increased to meet requirements. The U.S. power generation industry is facing challenging times. The Department of Energy has boosted spending for R&D on alternative fuel sources. Up to 70% of the nation's fossil fuel power plants in operation today are nearing the end of their designed service life.[84] The country is now looking hard at options for replacing these plants including fuel sources. If status quo for reliance on fossil fuel is the answer it must be considered that the nation is already at a record high for dependence on foreign oil imports and also at a record low for domestic oil production. It is risky to fully commit another generation to fossil fuel as a energy source for electricity production. The host countries producing most of the world's oil is becoming keenly aware of their own needs for oil and the future value of oil.

When looking at alternate solutions for replacing aging power plants it has to be understood that every proposal has adverse effects. Nuclear power was once thought to be the "save all" of electricity needs. For a while the very high costs of nuclear power had to be accepted because of the monopoly that electric utilities had on their customers. Now that deregulation has taken effect on electric utilities nuclear power is not at all competitive because it is twice as expensive as other fuel sources when all the real costs are accounted. Hydropower is actually reducing in electrical generation capacity in efforts to comply with coequal status for wildlife. The seemingly most wonderful sources like wind power for producing electricity have drawbacks. Land use and locations are obvious costs, but other factors such as one wind farm causing the death of 78 golden eagles in two years has environmentalists angered. The federal legal standard of protection for the golden eagle is "no losses."[85]

A solution, in part, to secure future adequate supply of electricity is to use MSW as a fuel source. Generating electricity through the burning of MSW at an incinerator is not a new idea, but has been around since the turn of the century. Electricity generated by a New York City incinerator was used to light the Williamsburg Bridge in 1904.[86] One ton of MSW equals about 1.5 barrels of fuel-oil heating value. With deregulation now allowing for Independent Power Plant (IPP) operations waste-to-energy facilities are emerging nationwide.

Fresh water resources and desalination:

Perhaps the most critical of all utility infrastructure deficits across America is water shortages. Garbage can stack up and humanity will probably survive for a long time. In most regards people, if forced to, can sustain life without electricity. Potable water. on the

other hand, is an absolute basic necessity for each human to continue living. The extent to which surface water sources will be developed has been maximized in the USA. Extensive pumping of groundwater is proving to result in several detrimental side effects. Lessons learned have been that pumping must be held to a rate no greater than the natural recharge ability or the supply being relied upon will diminish and geological subsidence will occur.

The nation is at a point of just meeting or failing to meet current demand for water and as stated before this demand is increasing along with population growth. Most city water works departments are looking to increase supply through alternative solutions. Desalination, used on Pacific islands (basically a small replica of the USA scenario), other countries, Florida and California, has gained tremendous support as a sensible solution. Afterall it is simply a quickening of nature's process of ocean evaporation and precipitation. Desalination only adds to the rate of naturally provided fresh water and in no way detracts from the natural cycle. The net effect desalination processes have on the ocean's constant volume of water is zero. Humans drink the very same water now that dinosaurs did a million years ago. The earth's global stock of water has not changed. There only difference is that now nature's cycle needs to be complemented by mechanical desalination to keep pace with the needs of earth's massive human population. Global use of fresh water rose from about 100 cubic kilometers at the start of the Industrial Revolution to 1,800 cubic kilometers in 1940 and has doubled since then to today's level of 3,600 cubic kilometers.[87] As shown in figure 4.2 desalination is sure to be a major element in future water resources management.

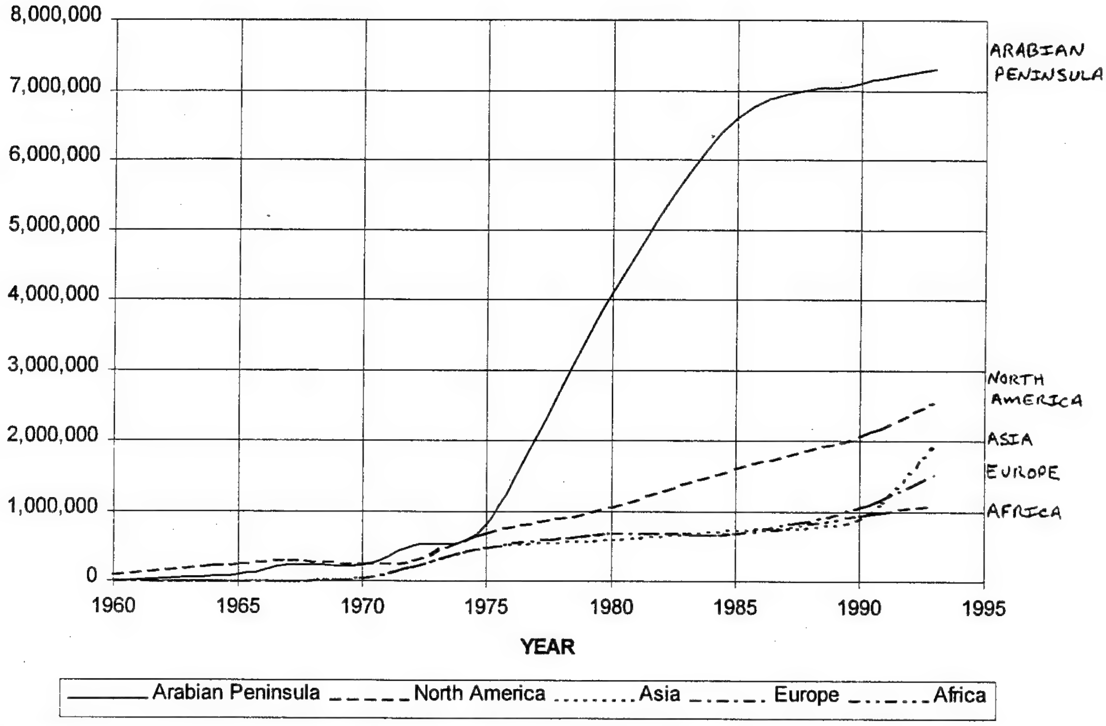


Figure 4.2 Daily cumulative capacity of all land-based desalting plants capable of producing 100 m^3/day of fresh water.[88]

Environmental regulatory requirements continue to become more stringent, the population is growing and competing demands on water resources are intensifying. Water supply adequacy is now a national concern. The Everglades massive restoration program is competing with the needs of the people of Seminole County, Florida who intend to increase pumping of the Floridian Aquifer. Inhabitants of the Colorado River Basin will have to survive severe hardships during the next sustained drought. Hydrologists are intensively searching for new groundwater resources in the Upper Snoqualmie Basin to supply Seattle's growing demand for water because neighboring Tacoma will not entertain conjunctive use. Cities are most interested in developing local sources of water to avoid paying premium rates and undertaking litigation for imported water. In the New York-New Jersey metropolitan area water emergencies are becoming more frequent events because of increases in water demand and lack of new supply additions. The water supply problem is further complicated by the conflict between purveyors obtaining supply from the same sources. No single particular approach to ensuring water is supplied can be necessarily deemed correct. Various combinations of methods are required in all regions. Conservation of water use by all is great for prolonging water shortages and is fundamentally correct, but relies entirely on human behavior. Curtailment or rationing of water is a harsh approach. Raising water rates to slow water use tries the patience of the

masses in an already stalled economy. Greywater reuse is excellent for the design of future water distribution systems, but is difficult to incorporate into the large existing city systems. A paradigm shift from traditional water resources management practices must happen and incorporate desalination to meet all foreseeable short and long-term needs. Santa Barbara, California out of forced necessity is leading the way with a plant operating that supplies up to 30% of the water for the 190,000 people in Santa Barbara, Goleta, and Montecito.

Cities most suited for the proposed integrated facility

The nicest climates and most desirable places to live in America, often coastal states and the southwest, are also the most disproportionate for water resources to meet demands. Some regions are better endowed with water resources than others. Of various climatic influences, precipitation appears to have the greatest effect on per capita residential demand primarily since it affects the lawn watering required. It is no surprise that arid geographical areas experience water shortages, particularly during droughts. The Santa Barbara shortage of natural fresh water sources is also true of much of coastal Southern California. In the next 20 years, the Metropolitan Water District of Southern California estimates that an additional 900 mgd of water will be needed in its region to meet municipal and industrial demands. At the same time there is, in the agency's own estimation, very little chance that it can obtain additional sources of water from its traditional importation of Northern California or Colorado River water. A significant fraction - perhaps 30 to 50% of the 900 mgd - will have to come from seawater desalting. New seawater desalting capacity of 18 mgd will have to be added - on average - each year for the next 20 years - to meet regional demand.[89] Shortages are likely to prove true for coastal cities in other parts of the U.S. where growing populations are outrunning traditional rain-fed water supplies. In such situations (which include Boston and New York), it is increasingly difficult if not impossible to capture major new traditional sources because of environmental and political pressure.

Coastal states are the most densely populated and places the highest value on real estate. Thus, they have the least space available for MSW landfills. These states also consume the greatest amount of electricity. Florida leads the nation in incineration capacity--with 17,000 tons per day--and continues to add more. The Central and Southern Florida Project to restore the Everglades has caused a major reduction to the fresh water supply yield depended on. Florida is now intently determined to make use of desalination and is planning its first large desalination plant. Virtually all states in the proximity of ocean water are prime candidates for the proposed integrated facility.

BENEFIT/COST RATIO TRADE-OFFS

The value of using heat from MSW combustion to generate electricity is understood and being used in America. Desalination is beginning to be used by public works departments, but is dependent on 100% of its required energy from an outside purchased source. The next step in public works progression is the combined cycle facility for MSW disposal to electricity generation to fresh water production. Determining benefit/cost ratios used to be a reasonably straight forward engineering economics drill. With the intangible societal values today, less and less is it acceptable to use solid monetary figures to evaluate whether a benefit\cost ratio is > 1.0. A brief economical analysis will be reviewed in chapter 5. The quantifiable and known intangible benefits and costs of this proposed integrated facility are useful in a feasibility study. Today's environmental "externalities" are almost always used as secondary and tertiary benefits submitted in demonstrating that a project has a benefit/cost ratio > 1.0. Loosely defined, externalities are the environmental or societal cost of pollution. Methods for quantification of externalities are highly complex and, at this time, still speculative. Nowhere is the crystal ball more cloudy than in forecasting probable societal values. Of late a value of $2 million per life saved has been used.[90] In the pursuit of quantifying externalities one excess cancer per million people over a 70-year period is the generally accepted risk standard for a municipal waste incinerator.[91] Change and uncertainty are more the rule than the exception. A hard lesson learned is that a "zero risk" goal is definitely unrealistic. A recent study reported that federal risk regulations cost nearly $600 billion a year, while benefits are about $200 billion a year.[92]

A detailed benefit/cost (b/c) presentation is beyond the scope of this thesis, but a basic example of the benefit/cost ratio for the proposed facility is included. Carefully considered trade-offs between benefit and cost will have to be completed before funding the proposed facility. Various approaches are used in decision-making involving trade-offs between and among values and priorities for a public works project. Bayesian probability, surrogate worth trade-off, and separable costs-remaining benefits are just a few ways that can be used to carefully consider trade-offs between costs and benefits for this proposed facility. Analysis becomes even more difficult when dealing with a combined facility, multipurpose outputs, and multiobjectives. For simplicity of this facility designed to support a population of 100,000 the b/c analysis here is based on a desirable weight system from 0 to 10, where 0 is not at all important and 10 is very important. These weights can be set by a board of city decision makers. The assignment of weights in this analysis was determined by author subjectivity and professional judgment when empirical sources were not available. Some of the benefits and costs overlap between MSW management, electricity production, and water supply. Every effort has been made not to double credit any single benefit or double penalize a single cost. Most costs and benefits that could be accounted for as being attributable to the project have been included in the analysis.

Municipal solid waste disposal

Each benefit and cost is assigned a decision maker's subjective weight value.

The most obvious benefit is the preserving of 90 acres of land from landfilling in a 10 year period. This land can be used for more economically productive purposes. With the long-term monitoring requirements for closed landfills this 90 acres, if landfilled, would be useless for development. Particularly when accounting for the risk that repairs to the liner or encapsulation may have to be made in the future. Communities are backtracking in efforts to recapture the value of land area occupied by landfills. At least 15 landfill reclamation projects are underway in America presently. The reclamation is accomplished by mining all MSW from a landfill and then burning it in a Waste-to-Energy facility. Hague, New York has reclaimed a seven-acre landfill to avoid capping it and monitoring it for 30 years. Hague now uses the reclaimed landfill area for cross country ski trails, snowmobile trails, and other recreation.[93] These uses for the real estate would not have been possible on top of a capped landfill. The logical approach would have been to process the MSW directly through a WTE facility in the first place without routing it through a landfill. **BENEFIT 9.0**

There will be public "Not in My Backyard" (NIMBY) resistance to the MSW combustor proposal. **COST 7.0**

Eliminated municipality exposure to public NIMBY resistance for 90 acres of landfill proposals. **BENEFIT 2.0**

A new MSW combustor will reduce the MSW volume by 95%. This means that 19 of 20 landfills are eliminated. Residual ash sent to a mono landfill causes land that cannot be used for other economically productive purposes. 1/20 x (9.0) = 0.45 It must also be taken into consideration that the integrated facility designed for 100,000 people will output about 1.8 MW of electricity which would otherwise be produced by a coal burning power plant. A 2.1 MW coal burning plant would have to dispose of 2 tons of ash per day.[94] This integrated facility processing 200 tpd will have to dispose of 10 tons of ash per day, thus; a 20% credit should be subtracted against the cost of the MSW ash monofill cost. **COST 0.4**

Having to only site one remaining of twenty potential landfills allows for greater flexibility to chose a site not close to groundwater. **BENEFIT 0.05**

Saved expense of not having to permit and litigate 90 acres of landfills over 10 years. **BENEFIT 7.0**

Saved construction costs of 90 acres of state-of-the-art landfills over 10 years. Including construction of the liners, leachate collection and treatment system, and encapsulation.
BENEFIT 3.0

The elimination of pollution generated from the manufacturing of ten layers of geotextile liners and hundred of miles of HDPE pipes for leachate collection for 90 acres of landfills over a ten year period. **BENEFIT 0.5**

The elimination of pollution from all construction equipment operations to construct 90 acres of high tech landfills over a ten year period. **BENEFIT 0.5**

Labor will be saved from the daily operations of 9 acres of MSW landfilling each year. Estimate two dozers operating and one gate keeper, six days a week for $15/hr wages.
(3 workers)(312 days/yr)(8 hrs/day)($15/hr) = $112,300/yr **BENEFIT 3.0**

Saved cost of POL, maintenance and depreciation of two dozers. Estimate 10 year useful equipment life, $100,000 purchase price for each dozer and $10,000 salvage value. POL is $20/day for each dozer and maintenance is $500/yr for each dozer.
2(100,000 - 10,000)/(10) = $18,000 depreciation per year
2($20/dy)(312 days) = $12,500 POL per year
2($500) = $1000 maintenance per year
Total = $31,500 per year **BENEFIT 0.5**

The air pollution is eliminated from the daily operations of two dozers over a ten year period. Credit for this is given in the electricity b/c analysis. **BENEFIT --**

There is an externality cost charged against the air pollution emissions released from a state-of- the-art 240 tpd MSW combustion facility. (this cost is accounted for in the next analysis on electricity production) **COST ---**

The "clean burning" methane that is collected from some MSW landfills and burned contributes to the global greenhouse effect. This contribution to the greenhouse effect from 90 acres of landfills over ten years is completely eliminated. **BENEFIT 0.5**

The expense is saved from the operating license renewal process for 90 acres of MSW landfills over a ten year period. **BENEFIT 1.5**

The expense is saved of filing for authorization under the Clean Air Act, Title V permitting to operate 90 acres of MSW landfills over a ten year period. **BENEFIT 1.0**

The expense is saved from long-term (30 yr min) monitoring and lab testing of 98 groundwater wells, long-term collection and treatment of leachate, and long-term

monitoring of MSW gas emissions. A single kilogram (2.2 lbs) of MSW in a landfill can produce 200 liters of methane and methane is 25 times more of a contributor per volume than carbon dioxide is to global warming.[95] Trying to trap and control methane from a large landfill for decades after closure is a major undertaking. Also the risk of contending with difficult repairs to a compromised MSW cell in the future is eliminated. No matter how tightly controlled the basic properties of the membrane are, accidental damage and perforations resulting from construction operations still occur. The principal motivation behind recent EPA revisions to Subtitle D regulations is to ensure the protection of the groundwater table. Therefore, a leak-free system is the goal for any and all landfill construction. A program designed to survey the bottom and side liners for leaks is a costly and painstaking endeavor. EPA staffing is not able to keep up with the current backlog of 2,300 landfill violations for groundwater, surface water, air and subsurface methane.[96] **BENEFIT 6.0**

There is less burden placed on having municipal wastewater treatment facilities used to process leachate from 90 acres of MSW landfill over a ten year period. **BENEFIT 0.5**

A safe assumption for a standard is that many cities must truck MSW 100 miles to a disposal site. This assumption is drawn from cities such as Portland, Oregon that sends its MSW to Arlington, Oregon 95 miles east of Portland. Portland started by using trucks for this task, changed to locomotives and is now back to trucking.
(200 tpd)(25 tons/truck) = 8 trucks per day for a 200 mile round trip.
(200 miles)/(55 mph) x (8 trucks) = 32 hours of labor per day
(32 hr)($15/hr) = $480/dy labor
Assume the trucks average between loaded one way and empty return 15 mpg.
(200 miles)(8 trucks)/(15 mpg) = 107 gallons of diesel fuel per day
(107 gal)($1.1/gal) = $118 per day for fuel. Round this figure to $120 to account for truck maintenance and highway maintenance from 30T truck traffic.
Total = $600/dy = $219,000 per year **BENEFIT 3.5**

Locomotives may be used in some cities for long distance MSW transportation. A potential reduction should be given to the transportation cost. **BENEFIT -1.5**

It is assumed that the 5% residual ash volume (22% residual ash weight) from the MSW combustor will have to be trucked the same 100 miles. 0.22($219,000) = $48,180 per yr
COST 0.9

There is a realistic probability of using ash in construction materials. This equates to less transportation cost to the ash monofill. **BENEFIT 0.05**

All aspects of MSW collection from generators remains the same for either the landfilling or combustion method of disposal. **B/C --**

Tipping fees for either method of disposal are about equal. **B/C --**

There is an expense to permit and litigate the 240 tpd MSW combustor. This includes the entire integrated facility with electricity production and desalination. **COST 6.0**

Construction cost to build the MSW combustor. This is included in the electricity production b/c analysis. **COST --**

Daily labor cost to operate the 240 tpd MSW combustor. One crane operator 24 hrs a day. All other labor for the integrated facility is accounted for in other analysis.
24 hr/dy($15/hr)(365 dy) = $132,000 yr **COST 3.0**

Cost to construct and maintain a hazardous type landfill for ash disposal. Hazardous waste landfills cost up to ten times as much as regular landfills to build and operate.
0.05(3)(10) = 1.5 **COST 1.5**

There is a cost of litigating against the classification of MSW residual ash as a hazardous waste. **COST 2.0**

There is a real cost of long-term monitoring and lab testing of 5 groundwater wells, long-term collection and treatment of leachate, and long-term monitoring of gas emissions from the ash monofill.
MSW incinerator ash may or may not be classified as hazardous waste depending on the chemical composition. (The assumption is made here that all MSW residual ash must be handled as a hazardous waste. It should be noted that the ash is biologically inert and does not produce methane. Part of the "ash" is just dirt and grit that comes with garbage. Court rulings have not held firm as to whether the MSW residual ash is a hazardous waste. One concern is that the nation's hazardous-waste landfill space is a valuable material resource that would be unnecessarily squandered on high volume, low risk wastes such as MSW incinerator ash.[97] Environmental groups and states continue to spend large sums of money to litigate the issue). **COST 2.0**

There is a risk associated with the probability that all MSW incinerator residual ash will have to be treated as a hazardous waste. The ash conveyors and all trucks would have to comply with hazardous waste manifesting. **COST 4.0**

(Note that under RCRA regulations all costs considered per ton of MSW ash is about ten times as expensive to dispose of in a hazardous waste landfill as opposed to an ordinary MSW landfill. This worst case scenario still saves 50% of the cost of just landfilling MSW without incineration). A few of the largest contributors that cause the increased toxicity level in MSW residual ash and are household batteries (lead and cadmium) and

drywall gypsum (dioxins and furans) from construction demolition. The 4.3 lbs/capita/day MSW figure used for design does not include construction debris, and car batteries are already banned from landfilling and incineration in most states.[98] It is estimated that three-quarters of the lead and cadmium in MSW residual ash comes from one source--household batteries.[99] These batteries also contribute the majority of other heavy metals (arsenic, zinc, copper, and mercury) found in MSW ash.[100] Removing household batteries from the MSW waste stream should not be that difficult of a challenge and would greatly enhance the chance that MSW ash would not be labeled as a hazardous waste. If cities get serious about battery collection each house could keep a one cubic foot box for collection. Twice a year the box could be turned in for monetary credit off of city garbage collection bills. Perhaps the box of dead batteries could be turned in to receive highway toll booth tokens, food stamps, public pool passes or even used to receive a $25 voucher to turn in as credit towards income tax filing.

After battery collection programs are in place and meaningful incentives are offered to the construction industry to keep drywall out of incinerators the MSW will seldom demonstrate toxic characteristics. At this point in MSW management operators of incinerators should only be required to keep records on methodical toxicity testing of outgoing ash. Any remaining trace metals in the ash are generally solidly affix to the ash and cannot leach. Providing that the facility lab records show Toxic Characteristic Leaching Procedure (TCLP) limits below EPA standards there is no reason not to place ash in ordinary nonhazardous landfills. The TCLP test assesses the likelihood of a material to leach enough constituents to reach toxic thresholds. Without batteries in the MSW incinerated and with ensuring that efficient combustion transpires the ash monofill leachate is mostly just salty water. This leachate can be mixed with agriculture spray irrigant.

Data from TCLP testing of MSW ash confirms that most every parameter is within acceptable EPA standards even without the removal of household batteries from the waste stream. A well established battery collection program will, without doubt, ensure that MSW residual ash is not classified as hazardous waste. Congress has been presented with credible findings that the risks of non-hazardous waste disposal are minimal and that incinerator ash may, in fact, be more environmentally safe than raw household garbage. Westchester County, New York does not collect household batteries and does incinerate MSW. Comparative tests were conducted by the environmental engineering firm of Malcolm Pirnie on the residual ash. As indicated by the values in table 4.2, leachate from an ordinary municipal landfill poses a greater threat than ash leachate.[101]

Table 4.2 Ash Leachate Vs. Sanitary Landfill Leachate (all units mg/l except pH)

Water Quality Parameter	Westchester Residue Ash Leachate	EPA TCLP Criteria	Typical Sanitary Landfill Leachate
pH	10.2 - 10.6	<2 or >12.5	
Aluminum	0.4 - 1.5	5.0	NR
Arsenic	<0.005	100.0	<0.003- 0.03
Barium	<0.02	1.0	ND - 1.1
Cadmium	0.01 - 0.05	5.0	<0.05 - 0.1
Chromium, total	<0.01 - 0.02		ND - 0.06
Chromium Hexavalent		0.05	NR
Copper	0.25 - 0.64		ND - 9.0
Iron	0.04 - 0.10		10 - 1,000
Lead	<0.05 - 0.13	50	0.02 - 1.0
Manganese	<0.01 - 0.02	0.3	0.1 - 50
Mercury	<0.005	0.2	NR
Nickel	0.06 - 0.14		0.1 - 0.8
Selenium	<0.005 - 0.009	1.0	NR
Silver	<0.02 - 5.0	0.05	NR
Zinc	0.006 - 0.031		0.5 - 135
Chloride	163 - 5,100		100 - 2,400
Sodium	155 - 3,600		100 - 4,000
TDS	3,090 - 15,900		1,000 - 10,000

NR - Not Reported
ND - No Detection Limit
Where a column is blank, no standard exists.

Potential benefit will be gained from battery collection programs and ash testing procedures. **BENEFIT 3.0**

Both nickel and arsenic are found in the ash from coal power plants. Thus, the 2 tons of coal ash that is saved by the integrated facility should be credited. **BENEFIT 0.01**

There is a cost to dispose of batteries after collection. **COST 1.5**

Environmental, health and safety externalities gained from household battery and gypsum collection. **BENEFIT 1.5**

Probability of battery and gypsum collection resulting in a court ruling that residual ash does not have to be disposed of as a hazardous waste. **BENEFIT 1.0**

Administration expense of battery and gypsum collection. **COST 0.05**

Energy cannot be created or destroyed. MSW combustion uses the absolute most amount of energy available in a ton of MSW. A landfill reclamation project in Lancaster, Pennsylvania excavates 2,000 cubic yards of MSW a week and processes it through a WTE facility. The Lancaster project yields a profit of about $30,000 per week based on the value of the energy produced.[102] Again, sending the MSW directly to the WTE facility would be more efficient than landfill reclamation. Using energy in methane collected from MSW landfills only makes use of a fraction of the energy available in MSW. (Additional credit is credit to this energy in the b/c analysis of electricity production). **BENEFIT 1.0**

Energy will be not available that is otherwise collected and used from some MSW landfills. (There is some logic to recovering methane from landfills to reduce pollution and create fuel, but landfills are not methane factories and this approach does not reduce the volume of waste). **COST 1.0**

There will be a 100% elimination of seagulls, buzzards, crows, wind, and rodents transporting and spreading MSW from uncovered daily operations at landfills.
BENEFIT 0.3

There is a probability that MSW residual ash will be used more as a construction material. Revenues will be gained from these sales, there will be less ash hauling and less ash monofill space will be needed. **BENEFIT 0.08**

<u>Production of electricity</u>

One site is used for the integrated facility vs. two or three real estate sites required for separate MSW incineration, power plant, and desalination facility. **BENEFIT 0.5**

The construction cost for a state-of-the-art WTE facility is $82,765 per ton of daily capacity on average.[103] This cost includes EPA permitting to approve construction which

was already accounted for in the b/c of MSW. EPA construction permitting costs about 10% of the total construction cost. At least 2% is subtracted because no cooling water towers and cooling water intake canals are required for the boiler steam cycle. (240 tpd)(1 - 0.1 - 0.02)($82,765/tpd) = $17.5 million for construction without the desalination portion. **COST 8.8**

The construction cost is saved to permit, build, and license another 2.5 MW power plant. Non-nuclear power plants cost about $1.5 million per MW to construct. Nuclear power plants cost over $3.0 million per MW to construct. Nuclear power plants will probably not be built again. ($1.5 million/MW)(2.5 MW) = $3.75 million **BENEFIT 1.6**

Useful Btu's are transferred from the power plant to the desalination units. This benefit will be credited in the Water Resources b/c analysis. **BENEFIT --**

Revenues received from the 2 MW exported from the integrated facility equal the revenues lost from a 2.5 MW fossil fuel plant that will not be operating. **B/C --**

The electricity used to operate the integrated facility is produced in-house and will not have to be purchased from an outside source. **BENEFIT 0.8**

Labor, operation and maintenance costs are slightly higher for the integrated facility 2.5 MW capacity as compared to the 2.5 MW fossil fuel power plant that will not be operating. This is because mechanical effort for the furnace is more intensive to maintain the stoker grates, combustion air must be more finely monitored from the control room to efficiently burn MSW, and more steam is being generated than is required for 2.5 MW when the desalination is fed. **COST 1.3**

There is much less decommissioning cost compared to any 2.5 MW portion of a nuclear power plant that may have to be built in the future. **BENEFIT 0.04**

2 tpd of ash disposal is saved from not operating a 2.5 MW coal power plant. This benefit is credited in the MSW b/c analysis. **BENEFIT --**

Ten tons of ash is disposed of from the integrated facility each day. This cost is accounted for in the MSW b/c analysis. **COST --**

ALL AIR POLLUTION EMISSIONS ARE SUMMED AND ONE COST IS ASSIGNED.

The incineration of MSW does have an environmental impact. Of course it does, as does everything else, from prairie grass fires to a person's last exhale. The integrated facility emits air polluting gases. Dioxins and furans are the main concern. Other emissions often

focused on in combustion is NO_x, SO_x, CO, particulates, lead, beryllium, VOCs, fluorides, and mercury. Technologies are fast progressing for the reduction of stack emissions from coal burning power plants, fuel oil plants, and MSW combustors. The scope of this thesis does not encompass detailed statistical interpretation of various constituent emissions, but makes the point through some fundamental observations and assumptions. Engineering comparisons are of little value if the units are not consistent. The variety of units and measurement conditions used in stating emission levels makes comparison difficult and in some cases impossible. A comparable unit that can be understood and used is constituent air pollutant pounds per million Btu's of fuel combusted. The point is not just to show that WTE emissions are well under stringent EPA limits (ppm or ng/cf), but to attempt to assign b/c values for the project.

In the tables 4.3 through 4.6 the pounds per month listed for constituents are the result of one month of facility operation to support a population of 100,000. The columns left blank represent measurements that were not available for this report.

The controlled emissions listed for an MSW combustor are based on data from three average plants currently operating and the most recent Title V operating permit limits.[104]

Table 4.3 Ordinary MSW incinerator ***COST***

Stack Emissions	lbs per million Btu's	Pounds Per Month
Criteria Pollutants		
Particulates, PM	0.02265	1,223.1
Sulfur Dioxide, SO_2	0.1081	5,837.4
Volatile Organics, VOC	0.0039	210.6
Nitrogen Oxide, NO_x	0.3752	20,260.8
Carbon Monoxide, CO	0.2265	12,231.0
Lead, Pb	0.0024	129.6
Noncriteria Pollutants		
Sulfuric Acid Mist, H_2SO_4	0.0253	1,366.2
Hydrogen Chloride, HCL	0.0855	4,617.0
Hydrogen Bromide, HBr	0.0069	372.6
Cadmium, Cd	8.10×10^{-5}	4.374
Antimony, Sb	0.0005	27.0
Arsenic, As	2.46×10^{-5}	1.328
Mercury, Hg	0.0009	48.6
Beryllium, Be	3.46×10^{-7}	0.0197
Fluoride, HF	0.0047	253.8
Dioxins	1.97×10^{-9}	0.00011

There will be no air pollution emissions from the 2.5 MW of fossil-fuel plant operations that are eliminated. Other known constituents emitted from fossil-fuel plants, not listed for this report, are selenium, chromium, nickel, manganese, and cobalt. The SO_2 and NO_x emissions are based on data and projected data from twelve operating fossil-fuel power plants and their efforts to comply with phase one and phase two of the Clean Air Act Amendments of 1990. The 1.45 SO_2 emissions is a projection for 1998 and the 0.443 NO_x emission is a projection for 1997.[105] Figure 4.3 points out that feasibly the break even point for fossil-fuel power plant NO_x emissions will settle at 0.3 pounds per million Btu's. The question "how safe is safe?" is the only guideline when evaluating the safety/cost ratio. The ratio nears zero when the NO_x emission of 0.1 lb per million Btu is sought.

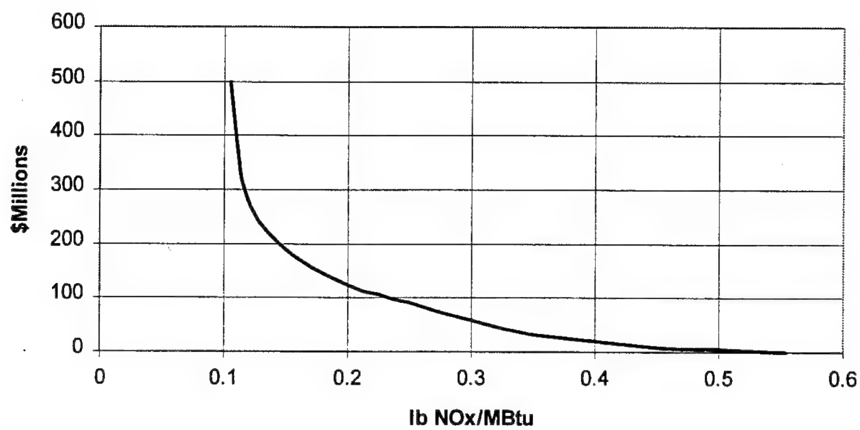


Figure 4.3 NO_x Emissions vs. Cost System-wide Basis[106]

Table 4.4 2.5 MW fossil-fuel power plant (coal fired) ***BENEFIT***

Stack Emissions	lbs per million Btu's	Pounds Per Month
Criteria Pollutants		
Particulates, PM	0.0406	622.6
Sulfur Dioxide, SO_2	1.2	18,391.1
Volatile Organics, VOC	0.0029	44.5
Nitrogen Oxide, NO_x	0.443	6,792.7
Carbon Monoxide, CO	0.00077	11.8
Lead, Pb	3.45×10^{-5}	0.529

Table 4.4 Continued

Noncriteria Pollutants		
Sulfuric Acid Mist, H_2SO_4		
Hydrogen Chloride, HCL		
Hydrogen Bromide, HBr		
Cadmium, Cd	4.15×10^{-6}	0.063
Antimony, Sb	1.20×10^{-6}	0.018
Arsenic, As	2.75×10^{-5}	0.422
Mercury, Hg	7.98×10^{-6}	0.123
Beryllium, Be	2.90×10^{-6}	0.045
Fluoride, HF		
Dioxins	**	

All air pollution emissions that would have been generated by the heat energy production for the desalination operation will not occur. The assumption is that fossil fuel would be used. There is a liklihood that natural gas would be used and a half credit is given except for NO_x.

Table 4.5 Emissions attributed to desalination heat requirement *BENEFIT*

Stack Emissions	lbs per million Btu's	Pounds Per Month	Half
Criteria Pollutants			
Particulates, PM	0.0406	1,733	867
Sulfur Dioxide, SO_2	1.2	51,228	25,614
Volatile Organics, VOC	0.0029	124	62
Nitrogen Oxide, NO_x	0.443	18,912	
Carbon Monoxide, CO	0.00077	32.9	17
Lead, Pb	3.45×10^{-5}	1.437	0.72
Noncriteria Pollutants			
Sulfuric Acid Mist, H_2SO_4			
Hydrogen Chloride, HCL			
Hydrogen Bromide, HBr			
Cadmium, Cd	4.15×10^{-6}	0.1772	0.0886
Antimony, Sb	1.20×10^{-6}	0.0510	0.0255
Arsenic, As	2.75×10^{-5}	1.1740	0.5870
Mercury, Hg	7.98×10^{-6}	0.3410	0.1705
Beryllium, Be	2.90×10^{-6}	0.1238	0.2476
Fluoride, HF			
Dioxins	**		

The truck or locomotive exhaust emissions from transporting 200 tpd of MSW to a landfill 100 miles away and daily dozer exhaust at the landfill will not happen.

Table 4.6 MSW transport and landfill dozer exhaust emissions *BENEFIT*

Stack Emissions	lbs per million Btu's	Pounds Per Month
Criteria Pollutants		
Particulates, PM	1.06	508.6
Sulfur Dioxide, SO_2		
Volatile Organics, VOC	1.35	647.8
Nitrogen Oxide, NO_x	1.23	590.2
Carbon Monoxide, CO	0.378	181.4
Lead, Pb		
Noncriteria Pollutants		
Sulfuric Acid Mist, H_2SO_4		
Hydrogen Chloride, HCL		
Hydrogen Bromide, HBr		
Cadmium, Cd		
Antimony, Sb		
Arsenic, As		
Mercury, Hg		
Beryllium, Be		
Fluoride, HF		
Dioxins	**	

**Europeans believe that fossil fuel power plants (both coal and oil), and car exhausts are a source that emits airborne dioxins. West Germany and Switzerland take the stance that there is no dioxin health risk at all from incinerators.[107]

Some offset credit is given because 200 tpd of MSW will not go to landfills. As raw garbage decomposes in a landfill, it emits various gases, including significant quantities of methane, mercury, hydrogen sulfide, and VOCs such as xylenes, toluene, and vinyl chloride. Many regions now require landfill gases to be flared which efficiently destroys VOCs.

In table 4.7 the cumulative air pollution emissions charged against the integrated facility are shown when supporting a population of 100,000. This is the sum of tables 4.3 through 4.6. Parenthesis signify a benefit gained. All other emission numbers are the externality cost of the integrated facility.

Table 4.7 Total air pollution emissions charged to the proposed facility ***SUM B/C***

Stack Emissions	Pounds Per Month
Criteria Pollutants	
Particulates, PM	(774.3)
Sulfur Dioxide, SO_2	(38,167.7)
Volatile Organics, VOC	(1,657.7)
Nitrogen Oxide, NO_x	(6,033.7)
Carbon Monoxide, CO	12,021.9
Lead, Pb	128.3
Noncriteria Pollutants	
Sulfuric Acid Mist, H_2SO_4	1,366.2
Hydrogen Chloride, HCL	4,617.0
Hydrogen Bromide, HBr	372.6
Cadmium, Cd	4.2224
Antimony, Sb	26.957
Arsenic, As	0.319
Mercury, Hg	48.306
Beryllium, Be	0.0985
Fluoride, HF	253.8
Dioxins	0.00011

When drywall is burned in MSW incinerators the level of SO_2 in stack gases rises markedly because of the calcium hydrated gypsum. Today no MSW combustors in the U.S. burn sheetrock. Most construction material is acceptable to burn in combustors except tar paper, drywall, asbestos, Pb paint and pipes. On the issue of dioxin, it has yet to be determined at what level dioxin harms human health. Too much of almost any substance will cause a human to die. Fifty aspirin taken at one time will kill almost anyone, yet aspirin is not consider to be a poison. The MSW combustion technology used today controls the release of dioxins to infinitesimal levels, far below the current stringent limits required by the EPA. When all of the technology available is used pollution control reaches a certain point when the costs of eliminating additional emissions generally rise sharply. Today's MSW combustors are as clean burning as societal values warrant. The modern mass-burn WTE plant is cost effective and uses air-pollution-control equipment that includes a selective non-catalytic reduction (SNCR) system, a spray-dry-absorber (SDA)/fabric filter (FF) dry scrubbing system, and an activated-carbon injection system. Consequently, even though MSW is used to fuel the plant, air emissions from the plant approximate those from a natural-gas-fired facility.[108]

TOTAL COST OF AIR POLLUTANTS. **COST 3.0**

There are potential global greenhouse effects contributed by burning MSW in the proposed integrated facility and saved by not using other fuels to produce the electricity and fresh water. Scientists continue to debate the relevance of the greenhouse effect and what causes it most. Data from the past 100 years suggests that all CO_2 emitted should have raised global temperature by 1^0F, but it is being confirmed that global temperature has risen by only $1/2^0$F. It is now believed that airborne sulfates actually help to cool the earth by promoting the release of radiant heat trapped below the ozone layer. Figure 4.4 demonstrates the theory.

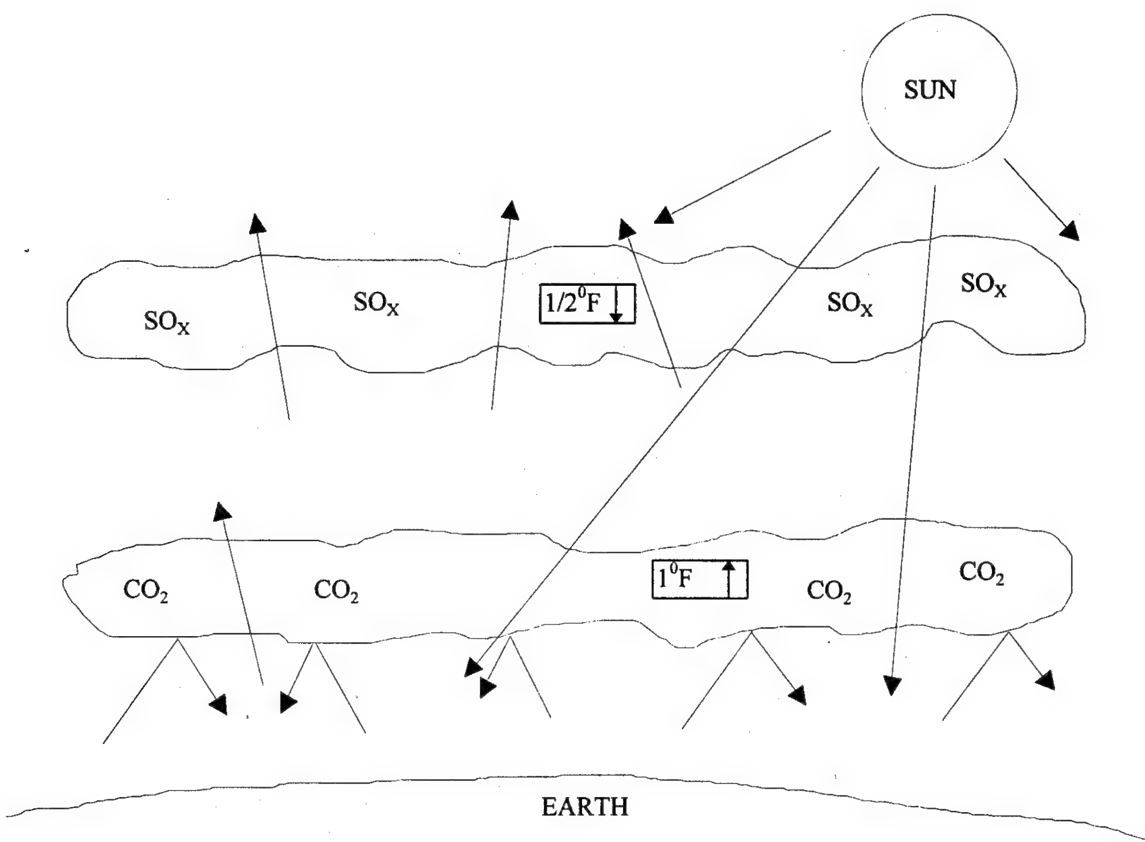


Figure 4.4 The global greenhouse effect

A single event such as the eruption of Mt Pinatubo has been credited with lowering the earth's atmospheric temperature by 1^0F. Another problem if Title V permitting were to allow for greater sulfate emissions is that acid rain would be increased in concentration. After considering all of the greenhouse debate it is appropriate to believe the integrated facility will have an equal effect on global warming as would the 2.5 MW fossil fuel plant and independent 1 mgd desalination plant that will not be operating.

B/C --

The land, ocean and fresh water resources are not harmed by oil drilling or coal mining to get fuel to operated the a 2.5 MW power plant and 1 mgd desalination unit. Air pollution from the equipment at these sites is also reduced. **BENEFIT 3.0**

The convenient part about using a MSW fuel source is that it is ready to use in its present state, contrary to complicated fuel processing like coal gasification or liquification, and petroleum distillation. Environmental harm to air and water is reduced by not having to process coal, crude oil or uranium for production of 2.5 MW electricity and 1 mgd fresh water. **BENEFIT 1.0**

If not coal as power plant fuel then the environmental risk from the transportation of fuel oil to power 2.5 MW of electricity production is eliminated. At least annually a large ocean tanker spill happens. Recall that the Exxon Valdez spilled eleven million gallons of oil into a sensitive Alaskan sound. In July, 1995 a major oil spill resulted in the Gulf of Mexico after a ship collided with a tanker. 100 barrels of fuel oil daily will not have to be transported to power just one 2.5 MW turbo-generator eliminated.[109] **BENEFIT 0.5**

Locomotive fuel and air pollution is spared from not transporting coal to produce 2.5 MW of electricity. Valuable railhead space is freed that can be better used for other commerce. A large land area to place the coal at the power plant is not required. 20 tons of coal is required per day to fuel a 2.5 MW turbo-generator. This coal volume would need a lay down area to store 620 tons for one month's operation.[110] **BENEFIT 0.5**

There is a probability that the battery collection and drywall incentives will be successful. This will help to reduce air pollution emissions. Removal of batteries will reduce the amount of mercury released into the atmosphere. Data also indicate that several metals in batteries (copper, zinc, antimony, chromium, and lead) serve as catalysts in the secondary formation of dioxins.[111] **BENEFIT 0.5**

There is a cost to execute the battery collection and drywall incentives program. This cost was accounted for in the MSW b/c analysis. **COST --**

Assume that many of the proposed integrated facilities will be built. There will be a reduced risk of electricity grid failures (i.e. blackouts) in a ring bus configuration because large power plants will be less relied upon. A utility with a large plant as shown in figure 4.5 needs a high reserve generation capacity to guard against the possibility that one plant representing a large percentage of capacity might go out of service. The desired reserve margin is set by a loss of load probability (LOLP) analysis designed to assure that major power outages will be limited to one day in a given number of years. Utilities often make sales to uninterruptible customers who pay a premium for assurance that electricity will not be lost. With many of the proposed integrated facilities being built less excess capacity will have to be paid for in primary power plants.

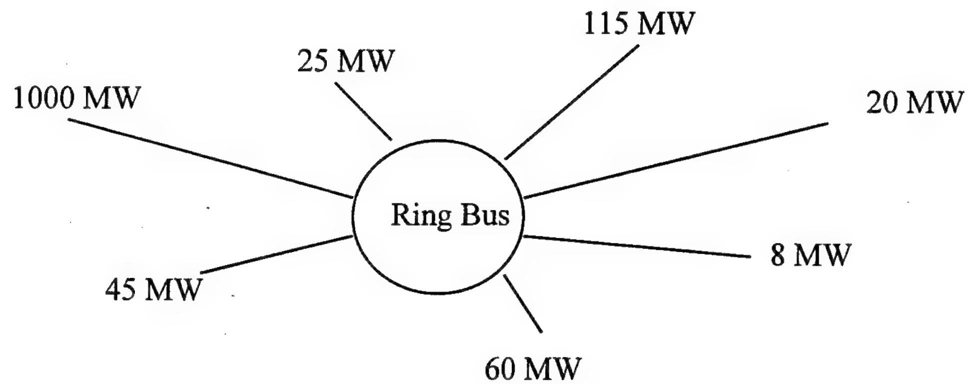


Figure 4.5 Electricity Ring Bus Configuration

If the 1000 MW power plant trips then the other plants are unable to carry the load, so the entire grid system will fail. With smaller plants if one plant trips off line then the other plants can collectively distribute the load. **BENEFIT 0.1**

The integrated facility will be located in the proximity of the customers served. This reduces the Btu's from fuel lost to I^2R losses when large power plants are required to distribute electricity long distances to consumers. Figure 4.6 depicts long distance transmission power losses. In America today about 7% of power plant generated KWhs are lost in transmission over long distances.[112]

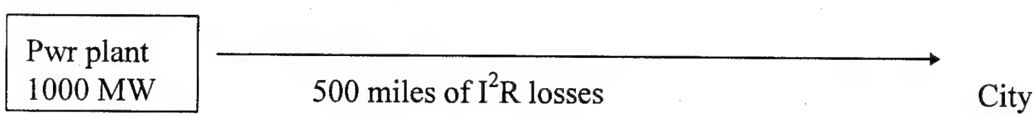


Figure 4.6 Losses of power in transmission lines

Electricity in America is sent as far as from the northwest to Southern California for use. This necessity will be less frequent when the proposed integrated facilities are built.

BENEFIT 0.2

Air pollution is reduced by not having to burn additional fossil fuel in power plants to overcome I^2R losses. This is accounted for in the collective emissions cost.

BENEFIT --

There is no expense to purchase fuel to produce 2.5 MW of electricity. (100 barrels of fuel oil)($30/barrel) = $3,000 saved daily. **BENEFIT 0.4**

The energy output in kilowatt-hours from the integrated facility is dependable (or firm). The Btu's supply by the city's own MSW is constant and not dependent on outside variables such as commerce or precipitation in the case of hydropower. **BENEFIT 0.01**
Water resources managers will have greater flexibility to satisfy stakeholders because there will be a reduced demand to use water for electricity production once WTE facilities are operating. **BENEFIT 0.01**

Not all energy consumption in the U.S. is expended to produce electricity. Of the energy sources America primarily uses, 100% of nuclear power is used to produce electricity, 100% of hydropower is used to produce electricity, 64% of coal consumed is used to produce electricity, 17% of natural gas consumed is used to produce electricity, and only 10% of oil consumed is used in power plants.[113] The proposed integrated facility allows for greater portions of coal, natural gas, and oil to be used for other required purposes.
BENEFIT 0.3

Flyash disposal is combined with and accounted for in the residual ash figures for MSW b/c analysis. **COST --**

Fresh water production

There is about a $4,950,000 cost to construct the desalination unit. **COST 9.0**

There will be a cost to obtain EPA approval permits for construction. This was accounted for in the MSW b/c analysis. **COST --**

Operating permits and licenses (renewals) are required for the desalination unit that will supply 6.4% of the water consumed by a city of 100,000. **COST 1.0**

Operation and maintenance, including labor, is necessary for the desalination unit supplying 6.4% of the water supply to a population base. **COST 3.0**

The cost is saved to develop an alternate 1 mgd water supply source. **BENEFIT 9.0**

The cost of water rights litigation, intense stakeholder negotiations, and searching for a 1 mgd new water resource is eliminated. Stakeholders such as native Americans and purveyors are becoming increasingly vocal and influential about their claims to water rights. A large competition for water is instream use vs. out-of-stream use. Seattle, for instance, is at the end of the life span for the current fresh water resources relied upon. For Seattle, getting water rights permits is extremely difficult and said to be the most

predominant obstacle in progressing forward with any fresh water resource project development.[114] **BENEFIT 3.0**

Environmental litigation to progress with a new fresh water source and transmission pipes or aqueducts to supply 6.4% of the water needs for a population base is avoided. **BENEFIT 2.0**

No harm will come to the environment and wildlife from the development and operation of a new 1 mgd fresh water source. The same follows for the transmission of the water supply. Presently in water resources management two main criteria are used to select resources: environmental impacts and cost effectiveness. This includes surface or groundwater. The proposed facility will also make available to engineers more options to minimize sedimentation problems. **BENEFIT 4.0**

Environmentalists will oppose any potential detrimental effect the desalination will have on the coastal ecosystem. Litigation is assured. **COST 1.0**

Assume the city is successful in court against the coastal ecosystem concerns. There is still a small probability that the increased salinity and higher temperature of the discharged brine will be harmful to marine life. The brine salinity concentration is 1.09 that of seawater and the brine temperature is 34°F warmer than the surrounding seawater. Environmental Impact Statements (EIS) completed for the desalination facilities in America today conclude that the massive ocean water reservoir normalizes the brine almost instantaneously.[115] **COST 1.0**

The operation and maintenance, including labor, for an alternative fresh water source to support 6.4% of demands for a population base is not required. **BENEFIT 1.0**

Construction costs are saved to place long distance water transportation pipes or aqueducts for 6.4% of the city's water supply. For each $4 spent on the development of a new water source $1 is the cost of the source and the other $3 is the cost of the transmission pipes or aqueduct.[116] By comparison to natural gas, electricity and others water is many times more expensive to transport. **BENEFIT 2.0**

The operation and maintenance costs, including labor, are saved for not needing long distance pipes to transport 6.4% of the city's fresh water. **BENEFIT 0.8**

No water will be lost to leaks, evaporation, and absorption in long distance water transportation of 1 mgd. Table 4.8 points out the significance of conveyance losses. **BENEFIT 0.9**

Table 4.8 Conveyance losses determined for Altar Pitiquito[117]

Material and type	Length (miles)	Losses (mgd/mile)
Concrete-lined canal	587	0.36
Earth canal	327	0.62
Pipe	436	0.17

Operating permits and licenses (renewals) for an alternative fresh water source to supply water to 6.4% of the population will not be required. **BENEFIT 4.0**

Revenues gained from the sale of water will be the same from the desalination unit as would be lost from the alternate supply source not developed. **B/C --**

The energy source for this desalination process is free. In fact, the supplier actually pays the proposed integrated facility $3.27 per million Btu's to receive fuel. Other desalination facilities not tied to MSW Btu cogeneration use fuel oil for flash evaporation or about 1.2 MW per mgd for EDR or R/O. On the west coast this means not only will Southern California require 1 mgd of water less to be sent from the north, but also will not be using electricity supplied by the northwest to operate desalination units. Electricity is saved by not having to pump aquifers, artificially recharge and then pump again. Approximately 7% of all electrical energy produced in Mexico is consumed to pump groundwater.[118] The same percentage or close to it holds true for Texas, Florida and other states.

BENEFIT 2.7

The expense of construction, operation and maintenance to reinject aquifers is saved. Rather than draining the aquifers and then artificially recharging to build stores for future use it is better to just not use the aquifers in the first place. Later, when really needed to supplement supply, selective aquifer withdrawals can occur. Landscape subsidence and saltwater intrusion in aquifers will be less of a problem if less overdrafting occurs.[119]

BENEFIT 1.0

Less water will be withdrawn from inland sources; thus more will be available for wildlife welfare, wastewater treatment outfall, hydropower, and navigation to use. Today water supply is normally considered to have a higher beneficial use than hydropower because water is used for human consumption and directly affects quality of life.[120] Not only does desalination prevent the withdrawal from inland water systems, but it generates 1 mgd of water to increase the fresh water supply system. Saltwater intrusion in coastal surface fresh water sources will be reduced and there will be less likelihood that further inland water quality problems will become an issue. **BENEFIT 0.9**

The potable water produced by desalination is of the absolute highest purity which easily meets both the primary and secondary EPA standards for drinking water. It can be mixed with other substandard local water sources to effectively double useful volume. The substandard water sources will already be of better quality because of the increased inland water availability for wastewater dilution. **BENEFIT 0.4**

By not developing more inland reservoirs to supply 6.4% of the fresh water to a population base less land resources will be placed under water. The real estate can be used for other productive purposes. **BENEFIT 0.1**

Fresh water is not required in the integrated facility to cool the boiler steam cycle in the 2.5 MW power plant. This saves considerable water from what would have to be dedicated to cool 2.5 MW of production in a conventional fossil-fuel power plant. Large volumes of both nonconsumptive and consumptive water is used by fossil-fuel plants. While some of the water returns to the river (nonconsumptive), approximately two-thirds will evaporate by design during the cooling process for a fossil-fuel plant. The average consumptive use of cooling water for a fossil-fuel power generating plant is 0.41 gallons per KWh.[121] An additional 24,600 gallons of fresh water saved daily is credited to the proposed integrated facility. **BENEFIT 1.0**

Less reliance on inland water sources will result in larger margins of safety for flood control using reservoir operating rules. The probability there will be large expenses for property damage is reduced. **BENEFIT 0.02**

Value is gained in the security to provide the city's own local fresh water supply without dependence on outside sources or rainfall. **BENEFIT 0.3**

SUMMARY

Forecasting values is an imperfect process. In this analysis good statistical techniques, combined with reasonable assumptions and common sense was used to provide public works managers with guidance to help prevent multi-million dollar mistakes. The benefits that have been projected for the integrated facility do not rely continuously on human behavior to recycle MSW and conserve electricity and fresh water, but realistically evaluates potential benefits and costs that should occur. Total scores for the benefits and costs of the integrated facility follows:

Utility	Benefit	Cost
MSW	43.99	29.35
Electricity	9.46	13.10
Water	33.12	15.00
Total	86.57	57.45

The benefit/cost ratio for the proposed integrated facility is 1.51. Some of the current public perceptions regarding MSW combustion still pose obstacles to development of the integrated facility. The main fears are greenhouse gases, dioxin, heavy metals, and toxicity of the ash. With increased recycling prior to combustion, high furnace temperature and at least 2 seconds residence time WTE facilities burn quite clean. Efficient recycling alone would eliminate about 85% of wind-dispersed dioxin.[122] The dioxin debate in Europe is dying out regarding MSW incineration because MSW combustors account for so little of the total dioxin emissions. Regarding MSW incinerator particulate emmissions, Benjamin Hershkowitz reported that it is estimated the "health threat from inhaling pollution is minimal--from four to sixty excess cases of cancer nationwide are expected annually from the operating MSW combustors in 1992".[123] Considering all of the real externalities and public fears there is perhaps a slightly greater adverse effect harming the environment and human health from the proposed facility when compared to alternative solutions. It can certainly be argued that all costs from an equal amount of electricity MWs produced with fossil fuel, nuclear power or hydropower, landfill practices and fresh water resources withdrawal are more damaging than the integrated facility. If externalities were not an issue then the simple economics of the proposed integrated facility are clearly more advantageous than three separate traditional solutions for MSW disposal, electricity generation and water supply. The USA now has roughly 147 WTE facilities operating that replace the energy equivalent of 33 million barrels of oil annually, reduces the balance of oil payments by a billion dollars, and produces enough energy to power 1.6 million homes.[124]

American spending on roads, bridges, school buildings and the rest of the basic infrastructure fell from about 4 percent of GNP in the 1960s to about 2 percent in the 1980s, two to three times lower than that of main principal competitors like Germany and Japan.[125] The price tag on externalities may be more than the U.S. can afford. Towns that subsidize recycling while cutting the school budget may find the public does not agree this is an ethical strategy. Environmental standards continue to reach for the impossible "zero impact". From the legal battles that ensue lawyers get a disproportionate share of "environmental" money. The nation should focus its limited resources on the greatest needs with the most cost-effective solutions and address them in order of priority. Many Americans are now questioning the logic in spending billions of dollars on permitting costs alone for public works projects in an effort to prevent the potential for one person in a million to contract cancer in a lifetime when compared to other risks that kill tens of thousands of people each year. America's population growth has placed unprecedented new demands on the public works system requiring that new projects progress. The

importance of meeting broad national objectives such as overall safety and sustaining National Economic Development (NED) should be emphasized when evaluating the b/c of public works projects.

It is quite an elusive process to reach consensus among economists, social scientists, and conservationists on the b/c of the integrated facility. The most difficult part is determining at what juncture societal impact begins or ends. Perceptions of benefits and costs differ depending upon assumptions of ownership and evaluation procedure. Such perceptions can lead to widely varying results. Wind-generated electricity has no emissions, but a monetized value must be placed on an endangered species of bird that gets chopped up in the spinning blades. A cost is associated with the visual blight that a wind farm puts on the landscape and the value of the land itself. Natural gas is often favored in generating electricity based on efficiency and lower CO_2 emissions at the power plant. For the natural gas option there is a cost in accounting for methane leaked into the atmosphere as a result of drilling and transportation. Methane is thought to be a far worse per volume contributor to the greenhouse effect than CO_2. There are those who would have projects protect fish and wildlife resources or scenic or historical sites at great cost, irrespective of measurable benefits. Some who are overly interested in water resource projects would have a basin developed as an end in itself.

Commodities that were thought to be infinitely renewable, like fish and plants, or seemingly omnipresent environmental assets, like fresh water, can only regenerate by themselves up to a certain point. Fish stocking and agriculture harvesting have been a part of normal life on earth for centuries. The time has arrived that it is now necessary to assist nature in the long-term production of fresh water. Desalination provides a reliable supply of high-quality water at the lowest environmental and economic cost. Clearly desalination is the best choice when considering that the primary competition on the Santa Barbara project was tankering fresh glacial water from western Canada. Desalination eliminates the two most severe disadvantages of traditional water projects: uncertainty in availability of supply and water rights disputes. Desalinated ocean water is available regardless of rainfall patters and without reducing supplies of other users or supplies needed to protect aquatic ecosystems.

Modernization, innovation, and diversification such as this “first” fully integrated facility are the keys to ensuring Americans have an adequate utility base in the future. Americans expect public works service, but are opposed to siting of public facilities, including sewage treatment plants, power plants, fire stations, new roads, airports, jails, mental patient quarters or clinics, homeless shelters, and MSW treatment, handling, or disposal facilities such as landfills, WTE plants, transfer stations, and recycling centers. Expectations for environmental protection are inconsistent. The same citizen who would not support opposition to campfires, fireworks, wood stoves, barbecue grills, and vehicle exhausts--all of which probably pose a greater threat to air quality than a modern WTE facility--is now an environmentalist with serious concern about air quality when a WTE facility is proposed in the community.

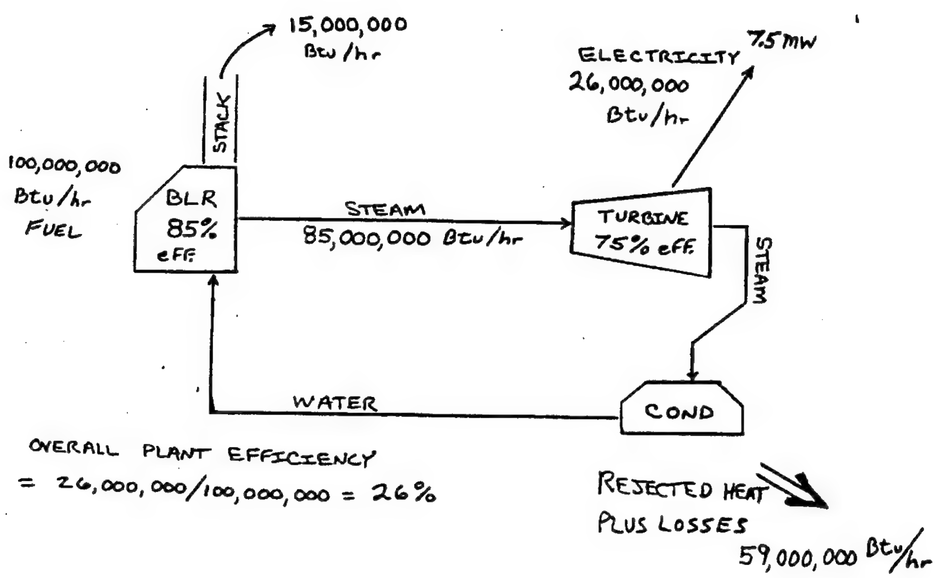
It is important to integrate environmental considerations in public works MSW, electricity and water challenges. Once synergy is working the cities should relentlessly look for ways to continuously improve; measure and report improvements.

CHAPTER FIVE
SUPPORTING A CITY OF A 100,000 POPULATION

Conservative interpretation of data is used to evaluate the utility requirements of the "typical" American city. Subsequently a facility is designed with the objective to strike a balance between the mechanical-energy waste heat from a WTE plant and the integration of other utilities, such as fresh water production. For the sake of brevity, only the preliminary phase of development is covered. The average electric utility generating plant normally converts its fuel energy to electricity energy at an efficiency from 25 to 30 percent. With cogeneration the combined plant uses roughly 65 to 70 percent of the energy in the MSW fuel. After designing the plant a determination is made to quantify just how much of a value this new facilty will add to a public works system both presently and ten years in the future with increased MSW quantities. A basic perspective of the economical analysis for the proposed integrated facility is also presented.

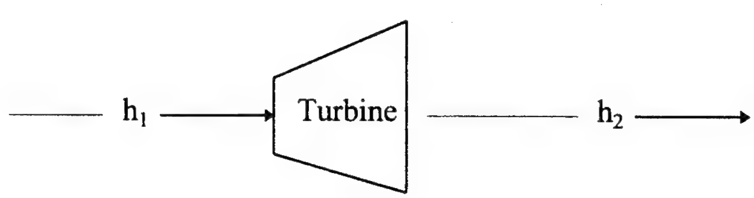
Design calculations

A simple steam cycle for a power plant use fire in a boiler to turn water to steam. The steam expands and spins a turbine. After exhausted steam leaves the turbine it is condensed back to water and returned to the boiler. The overall plant efficiency is a ratio of the electrical energy generated to the amount of fuel expended. This overall effeciency includes mechanical losses in areas such as the generator. The plants thermal efficiency does not account for mechanical losses. For any single component such as the boiler or turbine or pumps the thermal efficiency is simply the energy input divided by the useful energy output. An example of a basic steam cycle is shown below.



Before spending the time to design a cogeneration facility it is important to gain a basic understanding as to why cogeneration is incorporated. A typical fossil-fuel power plant, without cogeneration, has an overall thermal efficiency of 35 to 43 percent. The design of cogeneration applications into a power plant can increase thermal efficiency by as much as 50 percent.[126] A brief example of the value cogeneration adds to a small turbine-generator is shown by comparing scheme 1. with cogeneration and scheme 2. without cogeneration. A boiler generates 50,000 lb/hr of superheated steam at 1,000 psia and 900°F. One alternative is to expand this in a Turbine-Generator (TG) set to a 200 psia exhaust and use the 200 psia steam in another process (i.e. desalination). The other alternative is to expand the superheated steam in the TG to a 1 psia exhaust; thus generating electricity alone in the power plant.

Scheme 1.



Steam Table $\qquad$ $h_1 = 1{,}448$ Btu/lb

$s = \text{const} = 1.6121$

Exhaust 200 psia and s leads to ..... $h_{2S} = 1,258$
h_{2S} is an enthalpy state between fluid and gas.
(Typical TG efficiency = 70%) This percentage amounts to the energy value of electricity generated divided by the amount of heat enrgy used by the turbine.
conversion Btu to KW is 3,413.

$P = 50,000$ lb/hr(1,448 - 1,258) Btu/lb(0.7/3,413) = 1,948 KW

The final enthalpy is available in the process steam. According to the principle of entropy change increase,[127] even through the net entropy change of any portion of steam moving through a cycle is always zero, incremental entropy increases across a turbine due to internal steam heating as a result of temperature gradients and friction does occur.

$eff(h_1 - h_{2s}) = h_1 - h_2$
$0.7(1,448 - 1,258) = 1,448 - h_2$ $\qquad h_2 = 1,315$ Btu/hr

Assume the cogeneration process can productively use 70% of the cogeneration energy (i.e. exhaust steam from the turbine).
Total energy use = TG + Cogen process
= 1,948 KW(3,413 Btu/KW) + 50,000 lb/hr(1,315 Btu/lb)0.7
= 52,673,524 Btu/hr useful energy

Scheme 2.
In this alternative the objective is to gain the maximum possible KW capacity from the TG without allowance for cogeneration use.

$h_1 = 1,448$ Btu/lb
$s_1 = 1.6121 = \text{const} = s_{2s}$

Steam Table (saturated steam) @ 1 psia $s_g = 1.9782$ $\quad s_f = 0.1326$

Solve for steam quality (x)
$s_{2s} = xs_g + (1 - x)S_g$
$1.6121 = x(1.9782) + (1 - x)(0.1326)$ $\qquad x = 0.80$

@ 1 psia $\quad h_g = 69.7$ $\qquad h_g = 1,106$
$h_{2s} = 0.2(69.7) + (1,106) = 900$ Btu/lb

Turbine efficiency should be slightly higher for a condensing TG vs. a back-pressure turbine. Use TG eff = 75%
$P = 50,000(1,448 - 900)(0.75/3,413) = 6,016$ KW
6,016 KW(3,413) = 20,533,660 Btu/hr useful energy

The productive energy output is more than doubled with a congeneration design. It is clear that the use of cogeneration is the most energy efficient.

CALCULATIONS FOR THE PROPOSED INTEGRATED FACILITY

All of the numerical figures used throughout the following calculations were specifically chosen with a conservative angle. The point is to prove what minimum advantage will be gained from the development of the proposed integrated facility. The facility will be designed to combust the MSW generated by 100,000 people. The capacity for initial construction is designed to support the population for ten years without requiring expansion. This engineering approach is a common practice to allow for city growth and MSW surges from floods, holiday season, etc.

One of America's best WTE facilities is in Marion County, OR.[128]
Population of service area
210,000
MSW MGMT
0.5% landfilled
77% incinerated
22.5% recycled

Design capacity is 550 tpd
Current MSW flow into the WTE facility is 510 tpd

(510 tons/dy)(1/0.77)(2,000 lb/ton)(1/210,000) = **6.3** lb/capita/dy

Following the same logic for 15 WTE plants around the USA, many of which are in communities that recycle, an average of **8.9** lbs/capita/day, was calculated.

In these 15 service areas the average zoning mix is 53% residential and 47% commercial.

Lakeland, Florida happens to have the same population as the typical city being designed for here.[129]
Population of service area
100,000
MSW MGMT
42% landfilled
58% incinerated

Current MSW flow into the WTE facility is 275 tpd. This equals **9.5** lbs/capita/day.

The EPA estimates currently American's generate **4.3** lbs/capita/day.[130]
One MSW combustion in Pennsylvania receives nearly **20** lbs/capita/day.[131]

Personal observation is that a household of two people, after efficient recycling, still places about 35 lbs of MSW per week out for disposal.
(35 lbs/wk/2 people)(1 week/7 days) = 2.5 lbs.
Assume that half of the MSW each American disposes of is generated away from the home such as at work, school, daily business and pleasure in town. So, 2.5(2) = **5** lbs/capita/day

Other credible sources calculated MSW generated in America in 1989 at **5.3** lb/cap/dy.[132]

Japan has conceded that about 30% recycling is about the optimum possible. The current USA national recycling average is 17%. It is not clear whether the 17% reported is curbside programs in effect, collection or actual complete recycling. American authority Harvey Alter, having twenty years of experience with MSW, has branded the over-25 percent recycling targets of many states and cities as "unrealistic".[133] Most experienced practitioners mention 15 percent as a more realistic figure for the remainder of this century.[134]

The design assumption is that the typical city recycles at an optimum 25% and after the WTE facility removes ferrous metals for resale from the MSW received prior to combustion only 0.5% by volume landfilling is required. This is 0.5% by volume of the city's total MSW stream destine for direct landfilling. The 0.5% does not include the residue ash monofill. For the purpose of design the 5% by volume residual ash is the bottom ash and fly ash which must be disposed of after complete combustion. The ash is sent to a "monofill" which receives only ash. A total of 5.5% landfilling will still be required by the city.

Using the most conservative 4.3 lbs/capita/day
4.3 - 0.25(4.3) - 0.005(4.3) = 3.2 lb/cap/dy
3.2 lbs/capita/dy(100,000 pop)(ton/2,000 lb) = 160.2 tpd

Another method is to proportion the thesis facility to the Marion County facility which is a conservative 6.3 lbs/capita/day; well below the 8.9 average.
(100,000/210,000)(510 tpd processed) = 243 tpd

An average will be used
(160.2 + 243)/2 = 201.5 tpd
200 tpd is available to be processed in the typical city today.

DESIGN THE FACILITY CAPACITY TO ACCOMMODATE GROWTH.

Recent statistics document that the American population is growing by 1% annually. This population growth rate may become slightly smaller in decades to come. The amount of MSW discarded in America is growing by 1.8%[135] annually and this 1.8% growth is getting larger by a factor of 4.5% per year.[136] To clarify this means this year garbage generation will increase by 1.8% from last year. Next year's MSW growth will be 1.8(1.045) = 1.88%.

The 4.5% factor for increasing MSW growth rate will not be used.
The facility capacity ten years after construction must be (200 tpd)$(1.018)^{10}$ = 239 tpd
Design for **240** tpd capacity.

The public works facilities engineer should seriously consider designing the WTE capacity for 250 tpd or even 300 tpd. It is hard to predict population growth and even harder to predict future political arrangements that might contract to receive MSW from neighboring counties. The 15 WTE plants referred to were all designed for a thirty year service life. One third of those plants are processing the maximum design MSW capacity now and the plants are only ten years old.

For the design of this proposed facility 240 tpd of fuel will be used.
The boiler efficiency for the Guantanamo Bay, Cuba Naval Base facility is **85.5** Percent.[137] This means that for each 100 Btu's of fuel burned the boiler produces steam carrying 85.5 Btu's. The other 14.5 Btu's is lost out the stacks, to tube cracks and radiation.

The Marion County, OR WTE facility realizes a MSW fuel heating value of 4,300 to 4,700 Btu/lb.[138] The average is 4,500 Btu/lb. The boiler is designed to process 550 tpd of MSW to produce 133,446 lbs/hr of steam @ 655 psig/700°F.[139]

psia = psig + 14.6   655 + 14.6 = 669.6 psia

Stm Table ..... enthalpy = h = 1,346.9 Btu/lb

1,346.9 Btu/lb(133,446 lbs/hr) = 179,732,332 Btu/hr

550 tons/day(2000 lb/ton)(day/24 hr)(4,500 Btu/lb) = 206,250,000 Btu/hr

Blr eff = 179,732,332/206,250,000 = **87.1%**

Use **85%** boiler efficiency for thesis design.

Various sources report the heating value of MSW to range from 4,000 to 7,000 Btu/lb. Both the values of 5,000 Btu/lb and 4,600 Btu/lb are commonly used in design. A value of **4,500** Btu/lb will be used for this thesis design.

240(2000)(1/24)(4,500)(0.85) = 76,500,000 Btu/hr

To choose superheater outlet steam pressure and temperature three operating boilers were considered.

Guantanamo Bay	625 psig/825°F
Marion County	655 psig/700°F
Standard ship	600 psig/700°F

For this design to be well within a superheated steam state **600 psig/700°**F will be used.[140]

Stm Table ...... h = 1,350.9 Btu/lb

Figures 5.1 through 5.3 in appendix A can be referred to for visualization of calculated parameters.

Superheater outlet steam

76,500,000 Btu/hr(1/1,350.9 Btu/hr) = 56,629 lbs/hr

After the superheater outlet the steam will basically split in three directions. 1.) Power plant auxiliary steam, 2.) Desalination plant auxiliary steam, and 3.) TG. The power plant auxiliary steam is used for gland seal systems, air ejectors (A/E), turbine pumps, etc. The desalination plant auxiliary steam is used to remove noncondensible gases (NCG) from the incoming seawater. Removing NCG from a liquid increases the thermodynamic heat transfer properties and prevents corrosion.

In a modern 1 MGD Low Temperature, Horizontal Tube, Falling Film, Multi-Effect Desalination Plant the NCG system steam requirement (@ 150 psig) is 1,300 lb/hr.[141] The proposed facility should produce about 1 MGD of fresh water.

56,629 - 1,300 leaves 55,329 lb/hr for the power plant auxiliary steam and TG.

A determination is made for proportioning the 55,329 lb/hr of steam to the power plant auxiliary steam and TG. On average among various power plant configurations the ratio of main steam routed to auxiliary systems vs. main steam flowing through the TG is 10 percent. For example a boiler that produces 55,000 lb/hr would send 5,000 lb/hr to auxiliary systems and 50,000 lb/hr to the TG. (i.e. 5,000/50,000 = 0.1)

The proposed facility will use steam pumps where practical instead of electric pumps. Economically, steam turbine pumps cost only one quarter of what an electric motor would cost to operate. The example, consider a 230 gpm water pump requirement that is 70% efficient. An electric motor (90% eff) would cost \$20,142 annually to power the pump and a steam turbine drive (95% mechanical eff) would cost \$4,595 annually to power the pump.[142]

In the proposed facility steam powered pumps can be used to move liquids such as boiler feed, distillate, brine blowdown, seawater booster, coolant discharge, and export pumps. Electric motors are still wisest for the Force Draft Blower response requirements, seawater intake and circulatrion pump displacement requirements, and condensate and condensate make-up pumps. Because more steam will be used for auxiliary requirements in the proposed facility a **0.15** proportion will be used to divide main steam in the power plant to the auxiliary systems and TG.

0.15 = x/(55,329 - x) x = Pwr plant aux stm
= 7,217 lb/hr

TG stm = 48,112 lb/hr

The TG will receive superheated steam @ 614.6 psia/700°F and exhaust steam @ 34.6 psia/260°F. A back-pressure TG is a more efficient turbine choice vs. a condensing type turbine. Back-pressure turbines provide much better ability for heat removal than a condensing type steam turbine does. Back-pressure turbines are effective for TGs smaller than 10 MW and are currently being used up to 26 MW. If a back-pressure turbine is used for electricity generation greater than 10 MW the TG becomes too sensitive to tripping off line such that the risk of tripping does not justify the increased cogeneration benefits gained with a back-pressure turbine. Trip risk can be assessed and designed for at capacity < 10 MW. The back-pressure TG with 20 psig exhaust steam will provide the best balance between the prime mover and waste heat recovery.

After choosing a seawater inlet temperature and many calculative iterations a desalination ratio of product water to motive steam equaling 7.8:1 was determined. The motive steam does not include the 150 psig auxiliary steam used in the desalination NCG system.

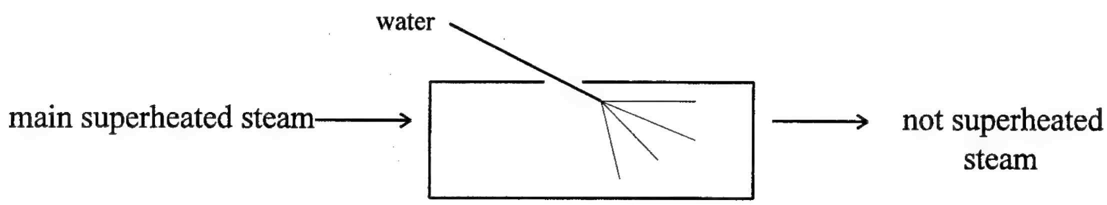
In Southern Florida and Gulf Coast states ocean water temperature is about 85°F. In California Pacific ocean water is about 65°F. For the "typical" American city seawater design temperature will be **75°F.**

All of the exhaust steam from the TG is used as desalination motive steam.
Motive steam = 48,112 lb/hr.

The desalination ratio is calculated as lbs of product water to lbs of motive steam.
V = Volume of product water.
V/[(24 hrs/day)(48,112 lb/hr)] = 7.8/ 1   V = 9,006,566 lb/day

(9,006,566 lb/day)(1 gal/8.345 lb) = 1,079,277 gpd
= 1.1 MGD

The first estimation of 1 MGD was slightly off.   x/1.1 MGD = 1,300/MGD
x = 1,403 lb/hr of 150 psig steam will be used by the desalination (hereafter desal) plant. This is actually main steam to which water was added to desuperheat the steam.



$$PV = nRT$$
$$\downarrow P \qquad T\downarrow$$

614.6 psia/700°F .... h_1 = 1,350.9 Btu/lb

150 psig = 164.6 psia
164.6 psia/382.4°F .... h_2 = 1,208 Btu/lb

Water @ 300°F .... h_f = 271 Btu/lb

A basic equation is used to calculate desuperheated water addition requirements.[143]
$W = \dot{m}[(h_1 - h_2)/(h_1 - h_f)]$
$\dot{m}$ = steam flow after desuperheater

W = 1,403 lb/hr[(1,350.9 - 1,208)/(1,350.9 - 271)]
= 186 lb/hr
Thus, the main steam from the boiler to the desal NCG system is 1,403 - 186 = **1,217** lb/hr
REPEAT

56,629 - 1,217 = 55,412
0.15 = x/(55,412 - x)
Pwr plant aux stm = **7,228** lb/hr
TG stm = **48,184** lb/hr

Desal product = V

V/[(24)(48,184)] = 7.8/1 V = 9,020,045 lb/day

= 1.1 MGD O.K.

BALANCE OF POWER PLANT HEAT AND MASS TRANSFER.

Refer to figure 5.1 (Appendix B)

h = 1,350.9 Btu/lb

System Heat **Input**

Boiler 56,629 lb/hr(1,350.9 Btu/lb) = 76,500,116 Btu/hr

System Heat **Output**

Power plant aux stm 7,228(1,350.9) = 9,764,305 Btu/hr
(before reduction)

Desal aux stm 1,217(1,350.9) = 1,644,045 Btu/hr
(before reduction)

TG 48,184(1,350.9) = 65,091,766 Btu/hr

The radiation, ventilation and other power plant steam losses are included in the 9,764,305 Btu/hr aux steam number.

65,091,766 + 1,644,045 + 9,764,305 = 76,500,116 Btu/hr O.K.

Calculate the enthalpy of the turbine exhaust steam. This, in turn, will be the desal motive steam.

h_1 = 1,350.9 Btu/lb $s_1 = 1.5844 = s_{2s}$

s_{2s} = part s_g + part s_f

@ 20 psig = 34.6 psia $s_g = 1.6880$ $s_f = 0.3797$

$s_{2s} = 1.5844 = x(1.6880) + (1- x)(0.3797)$ $x = 0.92$

@ 34.6 psia h_g = 1,166.9 Btu/lb h_f = 227.16 Btu/lb

h_{2s} = 0.92(1,166.9) + 0.08(227.16) = **1,092.5** Btu/hr

BALANCE OF DESAL UNIT HEAT AND MASS TRANSFER.
Refer to figure 5.2 (Appendix B)

System Mass **Input**
For a modern 1 MGD desal unit 2,850 gpm of seawater is drawn from the ocean. Using proportions

$\dot{m}$/1.1 MGD = 2,850/1 MGD $\quad\quad$ $\dot{m}$ = 3,081 gpm

3,081 gal/min(60 min/hr)(8.345 lb/gal)(1.025) = 1,580,988 lb/hr

Seawater[144] S.G. = 1.025
For seawater[145] @ 75°F/29.6 psia .... h = 43.1 Btu/lb

Motive steam input is 48,184 lb/hr, @ 260°F/34.6 psia .... h = 1,092.5 Btu/hr

150 psig aux stm input after desuperheater is 1,589 lb/hr
@ 382.4°F/164.6 psia .... h = 1,208 Btu/hr

System Mass Desal **Output**
Motive steam (condensate) = 48,184 lb/hr
@ 101°F/65 psia .... h = 69.3 Btu/hr

Distillate = 1,080,892 gal/day(day/24 hr)(8.345 lb/gal)
= 375,835 lb/hr
@ 107°/43.4 psia .... h = 75.3 Btu/lb

The seawater intake, product output and brine blow are directly proportional. For a 1 MGD unit brine is discharged at 1,500 gpm.
x/1.1 MGD = 1,500 gpm/1.0 MGD $\quad$ x = 1,621 gpm
@ 109°/26.6 psia .... S.G. = 1.03
h = 77.3 Btu/hr

Brine blow = (1,621 gal/min)(60 min/hr)(8.345 lb/gal)(1.03 S.G)
= 836,158 lb/hr

NCG condenser cooling seawater
= seawater in - distillate out - brine out
= 1,580,988 - 375,835 - 836,158 = 368,995 lb/hr
@ 101.5°F/26.6 psia ...... h= 69.8 Btu/lb

150 psig aux (A/E) condensate = 1,589 lb/hr
@ 110.5°F/65 psia ...... h = 78.8 Btu/hr

CHECK

Mass Input	1,580,988 lb/hr
	48,184
	1,589
	1,630,761 lb/hr
Mass Output	48,184 lb/hr
	375,835
	836,158
	368,995
	1,589
	1,630,761 lb/hr

System Heat **Input**

Seawater	1,580,988 lb/hr(43.1 Btu/lb) =	68,140,583 Btu/hr
Motive Steam	48,184(1,092.5) =	52,641,020
Aux Steam	1,589(1,208) =	1,919,512
Total		122,701,115 Btu/hr

System Heat **Output**

Motive Steam (condensate)	48,184(69.3) =	3,339,151 Btu/hr
Distillate	375,835(75.3) =	28,300,375
Brine Outfall	836,158(77.3) =	64,635,013
NCG Condenser Cooling Seawater	368,995(69.8) =	25,755,851
150 psig Aux (A/E) condensate	1,589(78.8) =	125,213
Total		122,155,603 Btu/hr

122,701,115 - 122,155,603 = 545,512 Btu/hr

545,512/122,701,115 = 0.0044 or 0.44%
Of the original heat input for the designed desal unit 0.44% is lost to radiation and vents. The older Guantanamo Bay desal unit loses 0.27% to radiation and venting. A more realistic ratio for the proposed integrated facility would be 7.85:1 for the desal unit.

Figures 5.1 through 5.3 in appendix B show the relationship of design parameters for the plant.

CALCULATE FINAL ELECTRICITY AND FRESH WATER EXPORTS

The TG will be designed using a 68% effeciency.[146] A 0.8 power factor for the generator is included in the TG effeciency.[147] Normal loading for a utility TG serving customer demands appears on the pattern in figure 5.4.

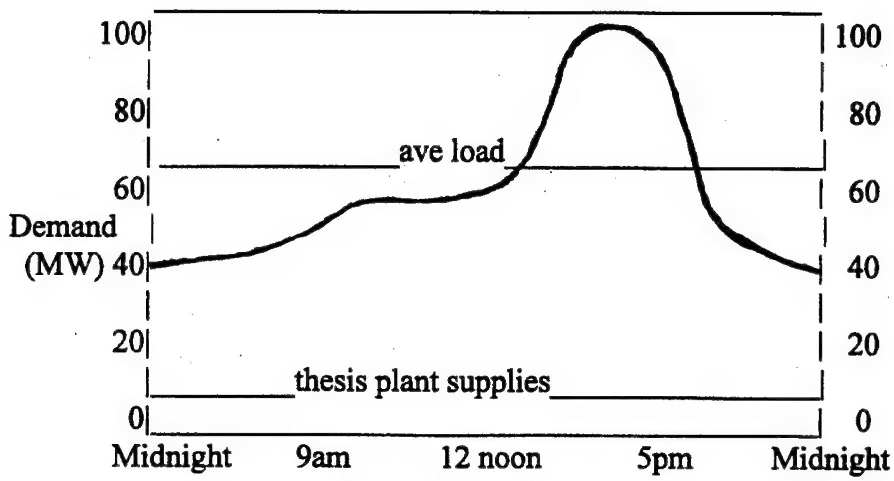


Figure 5.4 **Utility daily load pattern**[148]

The capacity for the turbine in figure 5.4 would have to be 100 MW and the average demand is 65 MW. The TG for the proposed integrated facility will be providing a constant base load to tie into the public works electricity grid. Therefore, the TG steam chest valves will operate fully open. The electric load drawn from the proposed facility will remain maximum and constant.

Electricity production from the proposed power plant is
P = 48,184 lb/hr(1,350.9 - 1,092.5)Btu/hr(0.68/3,413) = 2,481 KW
= **2.5** MW

The power plant design industry standard is that the combined rating of all auxiliaries in a modern plant may amount to 15% of the main unit rating.[149] The proposed integrated facility will use steam to power pumps vs. electricity were practical. Granted, the stoker grates will consume considerable electricity, but so would the coal handling mechanisms in a fossil fuel plant.

For the proposed facility in-house electricity usage is 0.15(2.5) = 0.375 MW. For customer export **2.125** MW is available.

A reasonable design assumption is that about 7,000 gpd of water per 1 MW capacity is required for boiler water/feedwater make-up and other fresh water uses in a power plant. Desal unit product output is 1,080,892 gpd.
1,080,892 - 2.5(7,000) = **1,063,392** gpd is available for customer export.
2.5(7000) = 17,500 gpd

BACK-UP AND BYPASS SYSTEM

In a condensing type TG the steam is being pulled through the turbine by the vacuum created by the hotwell in the condenser. For a back-pressure type TG the steam is being pushed through the turbine and must overcome the force of pressure in the exhaust. A system has been designed in this thesis power plant to ensure maximum electricity output of the TG considering MSW feed rate. The scenario is

1.) A mechanical problem occurs in the desal plant such that 20 psig cannot be received and used.

2.) As a result the motive steam input to the desal begins to back up to the power plant TG.

3.) TG back-pressure increases to 25 psig.

4.) A pressure transmitter (PT) located on the TG exhaust trunk measures the increased pressure of 25 psig and sends a signal to the Motor Control Center (MCC).

5.) The MCC responds by activating the seawater circulation pumps which starts the cooling seawater flowing through the condenser hotwell. Normally Open (NO) contacts will close to start the seawater circulation pumps.

6.) The temperature in the condenser is now low enough that the condenser is now in a standby mode to receive TG exhaust steam of necessary.

7.) The back-pressure of TG continues to increase because of problems in the desal facility. Once TG back-pressure reached 30 psig a safety valve in the TG outlet piping releases overburdened steam pressure and dumps to the condenser. Note that the safety valve arrangement is a 3 valve system with each valve having a range of pressure release increases.

35	fully open	40	45
	partially open		
30	closed	35	40
1		2	3

8.) As the desal plant is placed back into correct operation and begins accepting 20 psig @ 48,184 lb/hr, the full MSW (mass) rate, then the reverse process occurs automatically.

-The relief valves closes
-PT measures a pressure < 25 psig
-MCC opens seawater circulation pump contacts.

For a planned shut down of the power plant TG the desal plant will still operate at maximum capacity. Plant personnel will read step by step in the O & M manuals and do the following:
1.) Open the Motor Operated Valve (MOV) just in front of the turbine-bypass desuperheater.
2.) Open the MOV just behind the turbine-bypass desuperheater.
3.) Close the MOV just in front of the TG steam chest valve. Leave this MOV just slightly cracked to bleed steam for a rolling cool down of the TG.

A natural gas line is supplied to the boiler furnace. The natural gas is used for priming heat before MSW is added after furnace maintenance shut downs. Also, the natural gas is used when the MSW feed is stopped for boiler maintenance to ensure the remaining MSW in the furnace completes combustion at a high temperature. If needed the natural gas will be used to keep MSW heat above 1,265°F for environmental compliance. The worst air pollution emissions occurs as a result of low heat combustion. Gases below the 450°F temperature are conducive to dioxin/furan formation.[150]

The proposed integrated facility includes environmental design to minimize the impact of the increased salinity and increased temperature of the brine outfall. The salinity concentration of the brine is about 1.09 times the salt concentration of normal ocean water. The temperature of the brine discharge is 34°F higher than the normal 75°F ocean water. Several steps are used to lower the salinity and temperature differential.
1.) Mix the brine with all of the condenser cooling seawater out flow.
2.) Mix the brine in the pipe which discharges local secondary wastewater effluent.
3.) Use a one mile long, high-density polyethylene deep sea outfall pipe in the ocean or use an existing wastewater treatment outfall.
4.) Place the outlet of the discharge pipe at ocean mid-depth vs. seabed.

State-of -the-art electrostatic precipitators, scrubbers, and reverse-air fabric filters will be used in the design of the proposed facility to minimize air emissions.

The design calculations substantiate that the proposed integrated facility will function according to sound engineering principles. The design concept will work and can be easily formalized by a competent engineering firm .

Design drawings

Figures 5.1 through 5.3, in appendix B, are the drawings for the proposed integrated public works facility. These drawings provide a good visual of just how the mechanics of the plant are coordinated. Heat and mass transfer balance summaries are provided on the drawings.

Electricity & fresh water exports

The proposed integrated facility will add utility value to public works infrastructure. After evaluating data from numerous regions it was determined that on average power plant capacity is normally 2 KW per capita in a service area.[151,152] This capacity satisfies all municipal and industrial (M & I) demands. Thus, the typical America city of 100,000 population requires a 200 MW plant. The electricity use pattern of residential and commercial customer load demand on a power plant has peaks and averages as shown in figure 5.5. The TG capacity must be at least as great as the highest peak anticipated. Throughout the year a power plant will generate about 65% of its rated capacity for consumption.[153]

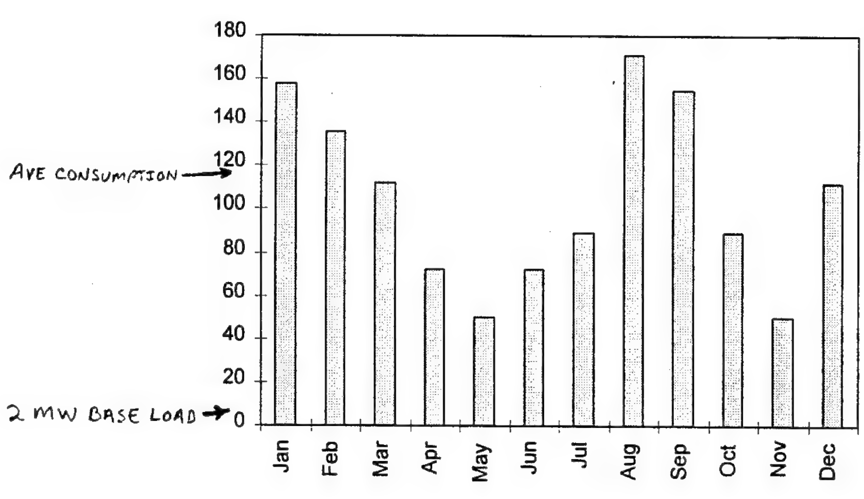


Figure 5.5 Annual electric utility load, MW[154]

A 1,000 MW power plant does not produce 1,000 MWhrs for each hour all year long. On average the 1,000 MW plant will produce 650 MWhrs for each hour of the year. The actual electricity produced for M & I **per capita** is 0.65(2 KW) = **1.3 KW**.[155] The TG in the proposed integrated facility will operate constantly at maximum production capacity to supply a portion of the city's base load requirement as shown in figure 5.5.

Nationwide consumptive use estimates for fresh water are 140 gpd per capita for M & I requirements.[156,157] There is little indication that per capita electricity and water usage will increase in the future.

For the 100,000 people today 200 tpd of MSW is available for processing in the integrated facility. The same calculations are used.
200(2000)(1/24)(4,500)(0.85) = 63,750,000 Btu/hr
(63,750,000 Btu/hr)(1/1,350.9 Btu/hr) = 47,191 lb/hr
Proportion with the designed facility
NCG system(1,217 lb/hr)(47,191/56,629) = 1,014 lb/hr
47,191 - 1,014 = 46,177 lb/hr

0.15 = x/(46,177 - x)
Pwr plt aux stm = 6,023
TG stm = 40,154 lb/hr

Electricity produced.

The electricity exported from the proposed integrated facility will flow to electrical switchgear and then over an interconnection line into the city's grid system.
P = 40,154 lb/hr(1,350.9 - 1,092.5)Btu/lb(0.68/3,413) = 2,067 KW
= 2.07 MW 0.85(2.07) = 1.76 MW exported

Water production is 24(40,154)(7.8)(1/8.345) = 900,758 gpd
(7,000 gpd/MW)(2.07 MW) = 14,471 gpd
900,758 - 14,471 = 886,288 gpd = 0.89 MGD exported

100,000 people today require 1.3(100,000) = 130,000 KW = 130 MW for M & I needs.
1.76/130 = 1.35% supplied

100,000 people today require 140(100,000) = 14 MGD of water for M & I needs.
0.89/14 = 6.4% supplied

For the typical American city today (100,000 population) the proposed integrated facility will

eliminate **94.95%** of MSW landfilling
supply **1.35%** of M & I electricity
& supply **6.4%** of M & I fresh water

As the city grows the population in 10 years will be 110,462 people. At that time the city will require 1.3(110,462) = 144 MW.

The city in 10 years will require 140(110,462) = 15.5 MGD of water

For electricity 2.125/144 = 1.48% is supplied
For water 1.06/15.5 = 6.9% is supplied

Because MSW discards per capita are expected to increase, ten years from today the proposed integrated facility will

eliminate **94.95%** of MSW landfilling
supply **1.48%** of M & I electricity
& supply **6.9%** of M & I fresh water

These estimates were based on predictions of population and unit demands. A slight further advantage of water gained should be credited because this facility does not consume 0.41 gal per KWhr required by the 2 MW fossil fuel plant replaced.[158] Also the highly pure desal product water can be mixed with unusable substandard water sources to effectively double the amount of fresh water gained. Water that has excess dissolved minerals, making it too hard or water that has a pH imbalance is ideal for blending with the pure desal product.[159] Adding some of the construction and demolition debris stream to the MSW fuel would increase the utility percentage gains substaintially more.

OVERVIEW OF ECONOMICS

The average construction cost of 15 WTE plants is $74,926 per ton capacity.[160] These facilities were built about ten years ago. Account for 1% inflation $\$74{,}926(1.01)^{10}$ = $82,765 per ton capacity today.

Currently desalination units are being constructed for about $4.5 million per 1 MGD capacity.[161]

It was difficult to determine whether or not the purchase of land was included in the capital costs for WTE and desal facilities. It is assumed for this proposed integrated

facility the typical American city will be able to use its own land space which was saved by not landfillling.

Capital costs = 240 tpd($82,765/tpd) + 1.1 MGD($4,500,000/MGD) = $24,813,600

If the construction money is borrowed at a simple 9% annual interest rate for a thirty year period (the service life) and payments are made annually the annual costs are
A = 24,813,600(0.09734) = $2,415,355

1988 operations and maintenance (O & M) costs for 7 WTE facilities averaged $6,841 per MSW tpd actually processed.[162]
Accounting for inflation $6,841(1.01)^7$ = $7,335

Assume that the O & M costs for the desal unit follows the proportion of construction costs.
240(82,765) = 19,863,600
1.1(4,500,00) = 4,950,000
x/7,335 = 4,950,00/19,863,600 x = $1,828

Total annual O & M costs per MSW ton = 7,335 + 1,828 = 9,163
Annual O & M cost for the thesis facility = $2,015,860
The O & M costs include license renewals and permitting.

Today's average MSW tipping fee charged by 15 WTE facilities is $29.42 per ton. Accounting for inflation and the increased MSW generation over the years, the annual revenue received will be $2,486,232.

The average electricity rate charge for KWhrs sold by eight WTE facilities is $0.051 per KWh. Accounting for inflation and increased production over ten years, the annual revenue received for electricity sales will be $867,831.

Currently the nation's water rates are about $1/ CCF.
1 CCF = 748 gal
With inflation the integrated facility will receive $500,656 annually for water sold.

TOTAL ANNUAL COSTS = 2,415,355 + 2,015,860 = $4,431,215

TOTAL ANNUAL REVENUES = 2,486,232 + 867,831 + 500,656 = $3,854,719

It will cost the city $576,496 annually for this proposed integrated facility. This cost does not credit the financial gains from the landfill real estate now available for other purposes or the money saved by not transporting daily loads of MSW a hundred miles. The cost of

the integrated facility probably quickly becomes an annual financial gain when the saved cost from landfill and water project legal battles are included. Also, the WTE facility will receive revenues from the sale of ferrous metals separated from the waste stream.

SUMMARY

In the typical American city **4.3 pounds of MSW** is generated per capita per day. For a city of 100,000 people an MSW incinerator should be designed to dispose of **240 tpd**. That amount of MSW fuel will generated **56,630 lbs/hr** of steam at **600 psig/700^{o}F**. From the steam **2 MW** of electricity will be produced and **1 MGD** of fresh water will be produced. The value added by development of the facility is **94.95%** of MSW landfilling eliminated, **1.5% of electricity requirements met** and **7% of fresh water consumption provided.**

Every care was taken in the design calculations to provide realistic results. The design demonstrates that thermodynamically the facility analysis favors development of the proposed facility. The addition of waste oil, fuel oil or natural gas to the furnace while burning MSW would add even further to electricity and water product outputs of the proposed integrated facility. This also allows for continuous generation of electricity and fresh water in the absence of an MSW input. The residual ash monofill should be located out of the range of potentially contaminating groundwater and within reasonable transporting distance. The facility can be expected to be used for a 30 year service life and even a 50 year service life with predictive and preventive maintenance. The longer service life will add more to the economical adtvantage of the proposed facility.

SECTION III
"The Pilot Facility"

CHAPTER SIX
WHY TARGET GUANTANAMO BAY, CUBA FOR A TEST FACILITY?

In the fifty states the process to gain governmental approval and to clear the political path for the proposed facility would probably take many years. At Naval Station, Guantanamo Bay, Cuba (hereafter GITMO) the regulatory climate is not as intense as within the USA, there is no local community to protest the project with NIMBY strategies and there are few special interest groups to get involved with the construction of the proposed facility. GITMO has an MSW disposal dilemma, has no natural local source of fresh water, and must provide its own electricity. Per capita requirements on public works utilities in GITMO resembles that of a typical American city.

History of the naval base

The Naval Base at Guantanamo Bay was established in 1903. It is the oldest overseas United States naval base in the world and the only U.S. military base in a communist country. Water from wells on the base is brackish and the rainfall is insufficient to supply the need for fresh water even if it could be collected and stored. For more than half of a century a contract with the Cuban Government supplied fresh water for the base from the Yateras River off base. On February 6, 1964 Fidel Castro cut off water and electrical supplies to the base. The gates were then closed and the option of disposing MSW off base was also lost. Just two months later, the Navy began construction projects that would make the base self-sufficient, producing its own water and electricity. The initial completed complex contained four fuel-oil boilers rated at 100,000 pounds of steam per hour and three TG sets (each rated at 7.5 MW). A supplier in Loma Linda, California had excess multi-stage evaporators sitting in a field and ready for sale. The evaporators were purchased for installation near the power plant to use extraction steam from the turbines. The desalination units had a 6:1 performance ratio.

The resulting plant was an integrated electrical and water producing facility which produces fresh water and electricity like its smaller cousin found aboard ships.

Current status of the base

GITMO has been in operation for nearly 100 years and is expected to remain open. Three MSW landfills on base have been used to capacity and are closed. One remaining landfill is now full to capacity and is still being used. Open burning in this fourth landfill is the means used for reduction. NAVFAC has hired an A/E firm to evaluate options for further MSW disposal after the closing of the fourth landfill. Once the most appropriated alternative is selected the same A/E firm will proceed to design the new MSW disposal facility. All alternatives for the next MSW disposal facility are being considered. In 1977 a third multi-stage flash unit designated as GITMO 3 was added. In the 1980s the two original multi-stage evaporators were removed and replaced with two, more efficient, multi-effect evaporators referred to as GITMO IV & V. The two new evaporators are rated at a 12.2:1 performance ratio, but often get results in excess of a 13:1 economy ratio for the process.

SUMMARY

The naval base at Guantanamo Bay is an ideal site for demonstrating the proposed integrated facility. The current presidential administration is financially assisting the development of new, different from traditional, methods of MSW disposal, electrical production and water resources management being sought. A demonstration project for the proposed facility can proceed quickly, applications for licenses and permits, and other documents that will be required before final approval and implementation of the project will be easier than in any of the states and for GITMO the project can be federally funded under several programs. The Federal Rapid Commercialization Initiative (RCI), military construction and national defense are all prime funding avenues for this project. GITMO is a unique site that has a well controlled political atmosphere for this project and is within close proximity to the USA.

CHAPTER SEVEN
THE DESIGN

Behavior of the Naval Base community at Guantanamo Bay closely resembles that of the typical American city in terms of public works utilities. Per capita MSW discarded, effects of recycling, and the usage of electricity and water for M & I requirements are about equal to America's national average. For the generation of MSW about 65% is attributed to residential and 35% comes from industrial. One of the unique facets which influences GITMO is the support of Haitian and Cuban migrants. At times a population of nearly 50,000 migrants have lived on the base for months.

Municipal solid waste generated

Several sources were used to determine the amount of MSW that is being generated at GITMO. Those sources include extrapolation from quantified requirements listed in the NAVFAC refuse collection contract, the GITMO solid waste annual reports, personal interviews, and the scope of work developed by the current A/E hired to design a solution for further MSW disposal.

Detailed accounts of all inhabitants of GITMO are maintained. The population statistics include military personnel, civil service civilians, contractor employees, all dependents, and migrants (Cuban and Haitian). There was a first Haitian exodus which lasted from October, 1991 to June, 1993 and another Haitian exodus which happened from about December, 1991 to October, 1992. The peak of the two Haitian exoduses occurred in March, 1992 and reached 13,000 Haitians along with 2,500 Joint Task Force (JTF) military personnel supporting. There have been several Cuban exoduses. The most recent peaked at about 47,000 Cubans occupying GITMO and had decreased to about 25,000 by March, 1995. A few thousand JTF personnel were still at GITMO in March, 1995 to support the migrant operation.

Fleet personnel from visiting ships contribute to the generation of MSW throughout the base. Also, dumpsters are placed on the pier which ships use daily. Other than a small amount of medical waste all MSW at GITMO is being landfilled. Data for <u>all</u> MSW is consolidated in a solid waste annual report. The population at GITMO tends to vary significantly depending upon activities. The installation population figures on the report do not count migrants.

Data taken from the solid waste annual report:

October 1, 1990 through September 30, 1991

Installation population:	Resident	7,000
	Fleet personnel	1,500/wk
MSW		103,400 tons/yr = **283** tpd

October 1, 1991 through September 30, 1992

Installation population:	Resident	7,000
	Fleet personnel	1,500/wk
	JTF	2,500
MSW		2,850 tons/yr = **7.8** tpd
Construction demolition debris		975 tons/yr = 2.7 tpd

(Hurricane Hugo struck GITMO in 1992)

October 1, 1992 through September 30, 1993

Installation population:	Resident	6,500
	Fleet personnel	1,500/wk
MSW		11,300 tons/yr = **31** tpd
Construction demolition debris		9,300 tons/yr = 25 tpd

(Hurricane Andrew struck in 1993)

October 1, 1993 through September 30, 1994

Installation population:	Resident	4,500
	Fleet personnel	1,500/wk
	JTF	7,500

(Most dependents were ordered to leave the base August, 1994)

MSW	77,750 tons/yr = **213** tpd
Construction demolition debris	9,300 tons/yr = 25 tpd

A personal interview was conducted with the refuse contractor in March, 1995. The contractor does not collect construction demolition debris. The refuse fleet has eight haulers (3 of 35 CY and 5 of 25 CY compacted capacity). Prior to the arrival of the Cuban migrants 3 trucks ran daily and made 2 or 3 full trips to the landfill each. This equates to **56** tpd. Since the arrival of the Cuban migrants all 8 trucks run daily and each makes a minimum of 4 trips full to the landfill daily. This equates to **250** tpd.

Disregarding the construction demolition debris, the MSW average equals
(283 + 7.8 + 31 + 213 + 56 + 250)/6 = 140 tpd

Electricity consumption

The electrical load analysis was based on records obtained from the GITMO plant, and analyzed for production and consumption. This data does not include electricity which is produced separately for the JTF and migrants.

October 1, 1992 through September 30, 1993

Average consumption	11.24 MW
Peak consumption	18.50 MW

October 1, 1993 through September 30, 1994

Average consumption	10.70 MW
Peak consumption	18.80 MW

October 1, 1994 through March 12, 1995

Average consumption	10.21 MW
Peak consumption	13.79 MW

The JTF and migrants do not receive electricity from the power plant. Five 2.1 MW and numerous smaller portable generators supply electricity for the JTF and migrants.

Fresh water consumption

Daily reports from the desalination unit provide data on fresh water production and consumption. GITMO fresh water consumption very closely matches production (i.e. the desal units are operated at a rate to meet demands).

October 1, 1992 through September 30, 1993

Average consumption	1,680,106 gpd

October 1, 1993 through September 30, 1994

Average consumption	1,706,928 gpd

October 1, 1994 through 9 March, 1995

Average consumption	2,284,767 gpd

Design calculations

There are four objectives in designing the proposed integrated facility for GITMO.

1.) Dispose of MSW and make use of presently unused MSW energy as a fuel.
2.) Use an energy efficient back-pressure TG arrangement to provide all of the motive steam for producing 2.5 MGD of fresh water.
3.) Reduce the wasted use of fuel oil which is now being rejected as condenser waste heat from the on site power plant. Each hotwell in the power plant currently is designed to reject 71,250,000 Btu/hr. That heat equals 515 gallons of fuel oil per hour.
4.) Record from this demonstration project the overall benefits of the prototype unproven integrated facility.

For the sake of simplicity it is assumed for the GITMO demonstration project of the proposed integrated facility all construction will be new. In a more practical sense much of the existing plant could be tied in and used along with the new facility. Certainly, GITMO evaporators IV and V should continue operation as part of the new facility. Most calculations and parameters for the demonstration project are the same as those used in designing a plant for the typical American city. Exceptions are noted.

Calculate the motive steam required to produce 2.5 MGD of fresh water. Motive steam is the heat source that flash evaporates the seawater in the desalination process.
(2,500,000 gal/dy)(dy/24 hr)(8.345 lb/gal) = 869,271 lb/hr

Design specifications for GITMO IV and V rate the production of each unit at a 12.2:1 ratio. This means that 12.2 pounds of fresh water is produced for each one pound of motive steam used. Actual performance records show that the multi-effect units at GITMO have a production as high as a 13:1 ratio.[163] A ratio of 12.5:1 will be used for the demonstration project.
(869,271 lb/hr)/ $\dot{m}$ = (12.5/1) .... $\dot{m}$ = 69,542 lb/hr

The same superheated steam parameters that are presently in the GITMO power plant will be used so that cross connections can be designed. Steam at the superheater outlet is 625 psig and 825°F. h = 1,419.7 Btu/lb

For a 5 MW TG a 73% efficiency is used.[164]

Power = 69,542 lb/hr(1,419.7 - 1,092.5)Btu/hr(0.73/3,413) = 4,867 KW

150 psig aux stm required by the desal unit
$\dot{m}$/2.5 MGD = (1,300 lb/hr)/1 MGD .... $\dot{m}$ = 3,250 lb/hr

desuperheater water = 3,250 lb/hr[(1,419.7 - 1,208)/(1,419.7 - 271)] = 599 lb/hr
Thus, the main steam from the boiler to the desal NCG system is
3,250 - 599 = 2,651 lb/hr

Total main steam that the boiler must supply = 69,542 + 2,651 = 72,193 lb/hr
Blr eff is 85%
72,193 lb/hr(1,419.7/0.85) = 120,579,297 Btu/hr required from fuel source.

MSW fuel source can supply
(140 ton/dy)(2,000 lb/ton)(dy/24 hr)(4,500 Btu/lb) = 52,500,000 Btu/hr

The remainder of the heat requirement will be supplied by cofiring fuel oil with the MSW in the furnace. 120,579,297 - 52,500,000 = 68,079,297 Btu/hr GITMO uses either Navy Special Fuel Oil or Diesel Fuel Marine. The caloric value of the fuel oil being used at GITMO is 138,335 Btu/gal. During full operation the newly proposed plant will burn 68,079,297/138,335 = 492 gal/hr or 12 barrels per hour.

Past records show that the GITMO plant has been burning about 40,000 gallons of fuel oil per day. The newly proposed facility will combust all MSW and be cofired with fuel oil. When greater amounts of MSW are received then the flow rate of fuel oil will be decreased or when water demands increase then the fuel oil flow rate will be increased. Alone the 5 MW Turbine-Generator (TG) will not be sufficient to supply electricity for the all of the base requirements. A 10 MW conventional thermal TG will also have to be run. The steam chest valves on the 5 MW TG will operate fully open at all times and the 10 MW TG will respond to load fluctuations. Past practice at GITMO has been to maintain three 7.5 MW TGs such that one may be shut down for maintenance and the other two could satisfy base requirements. Also, the base now has two 2.5 MW diesel generators and three 1 MW diesel generators as back up. One large visiting ship alone placed on shore power can increase demand on the power plant by 3 MW. It might be wise for the newly proposed facility to decommission one of the 7.5 MW TGs and keep the other two 7.5 MW TGs instead of bringing in a new 10 MW TG. An alternate motive steam system for desal linked to the main TG will permit maintenance to be conducted on the WTE plant while still producing fresh water.

BALANCE OF NEW POWER PLANT (5 MW) HEAT AND MASS TRANSFER.

System Mass **Input**
Boiler 72,193 lb/hr

System Mass **Output**
Desal aux stm 2,651 lb/hr
(before reduction)
TG 69,542 lb/hr 2,651 + 69,542 = 72,193 lb/hr
O.K.

System Heat **Input**
Boiler 72,193 lb/hr(1,419.7 Btu/lb) = 102,492,402 Btu/hr

System Heat **Output**
Desal aux stm 2,651(1,419.7) = 3,763,625 Btu/hr
(before reduction)
TG 69,542(1,419.7) = 98,728,777 Btu/hr

As with the typical American city the proposed integrated facility will not provide all the electricity needed. For GITMO the proposed facility will be located in the same compound as the main thermal power plant. Other than for desal requirements the main thermal power plant will supply the 150 psig aux steam for the entire plant. Also the present performance at the GITMO plant has 15% of TG electricity produced consumed by the power plant in house. This matches the industry standard. The main power plant will supply all in house electricity requirements and the full electricity production of the new 5 MW TG will be exported.

3,763,625 + 98,728,777 = 102,492,402 Btu/hr O.K.

BALANCE OF DESAL UNIT HEAT AND MASS TRANSFER.

System Mass **Input**
For a modern 1 MGD desal unit in the Caribbean 2,850 gpm of seawater is drawn from the ocean. Using proportions

$$\dot{m}/2.5\ \text{MGD} = 2{,}850/1\ \text{MGD} \qquad \dot{m} = 7{,}125\ \text{gpm}$$

7,125 gal/min(60 min/hr)(8.345 lb/gal)(1.025 S.G.) = 3,656,675 lb/hr

For seawater @ 85°F/29.6 psia .... h = 54.6 Btu/lb

Motive steam = 69,542 lb/hr

150 psig aux stm input after desuperheater = 3,849 lb/hr

System Mass Desal **Output**
Motive steam (condensate) = 69,542 lb/hr

Distillate = 869,271 lb/hr

The seawater intake, product output and the brine blow are directly proportional. For a 1 MGD unit brine is discharged at 1,500 gpm.
$\dot{m}/2.5$ MGD = 1,500 gpm/1.0 MGD $\dot{m}$ = 3,750 gpm
Brine blow = (3,750 gal/min)(60 min/hr)(8.345 lb/gal)(1.03 S.G.)
= 1,933,954 lb/hr

NCG condenser cooling seawater
= seawater in - distillate out - brine out
= 3,656,675 - 869,271 - 1,933,954 = 853,450 lb/hr

150 psig aux (A/E) condensate = 3,849 lb/hr

CHECK

Mass Input	3,656,675 lb/hr	
	69,542	
	3,849	
	3,730,066 lb/hr	
Mass Output	69,542 lb/hr	
	869,271	
	1,933,954	
	853,450	
	3,849	
	3,730,066 lb/hr	O.K.

System Heat **Input**

Seawater	3,656,675 lb/hr(54.6 Btu/lb) =	199,654,455 Btu/hr
Motive Steam	69,542(1,092.5) =	75,974,635
Aux Steam	3,849(1,208) =	4,649,592
Total		280,278,682 Btu/hr

System Heat **Output**

Motive Steam (condensate)	69,542(69.3) =	4,819,261 Btu/hr
Distillate	869,271(75.3) =	65,456,106
Brine Outfall	1,933,954(77.3) =	149,494,644
NCG Condenser Cooling Seawater	853,450(69.8) =	59,570,810
150 psig Aux (A/E) condensate	3,849(78.8) =	303,301
Total		279,644,122 Btu/hr

280,278,682 - 279,644,122 = 634,560 Btu/hr
634,560/280,278,682 = 0.0023 or 0.23% for radiation and venting. O.K.

SUMMARY

The one remaining active landfill at GITMO is expected to have a finished surface area of 70 acres. As of September 30, 1994 it was estimated to have 1.5 years of service life remaining. After receiving and supporting approximately 47,000 Cuban migrants the landfill quickly reached capacity. Open burning is used as a method to reduce the MSW volume in the landfill by 50 percent. The base is at a point now that it requires a new means of MSW disposal and the proposed new integrated facility is a viable alternative for a solution. A small residual ash monofill will be required to support the new facility.

Energy exhausted from the new back-pressure turbine provides enough heat to produce a maximum of 2.5 MGD of fresh water. Presently for the consumption of electricity and fresh water at GITMO about 40,000 gallons of fuel oil per day is being used. With the newly proposed integrated cogeneration facility the replacement of fuel oil with MSW as a heat source will save 9,100 gallons of fuel oil per day. The energy saving benefits of cogeneration through a back-pressure turbine further add to daily fuel oil use reduction. Half of the daily electricity requirements will be produced out of the new cogeneration plant. The result will be that half of the energy that was being rejected to the ocean by the main condensers will be eliminated. This amounts to approximately another 9,900 gallons of fuel oil consumption per day reduced. The total daily fuel oil savings will be 19,000 gallons after the new integrated facility is constructed. The reduction nearly cuts in half the present 40,000 gallons per day fuel oil consumption at the GITMO plant. With the assupmption that some of the present facility will be used in the demonstration project, simple 9% annual interest rate is used, and fuel oil costs $30 per barrel then the proposed new integrated facility will pay for itself in 3.5 years. After 3.5 years the newly proposed plant will generate $402,000 savings (profit) each month for the rest of its 30 year service life.

SECTION IV
Conclusion

CHAPTER EIGHT
STRATEGIC UNITED STATES LOCATIONS

Coastal cities in water deficient states will receive the most immediate and direct benefits from operation of the proposed integrated facility. It is noted that fossil fuel and even better, natural gas power plants are ideal for cogeneration applications to make fresh water, but does not also dispose of MSW. Electricity is being produced by using MSW as fuel in many states, but wastes heat that can easily be used in desalination. Perhaps California should be the first state to employ the proposed integrated facility. California has become the most water poor state when compared to its population which is projected to be 36.3 million by the year 2010. Cities throughout the United States that can gain the full 1.4% electricity and 6.4% fresh water production advantage are Seattle, WA, Tacoma, WA, San Francisco, CA, Los Angeles, CA, San Diego, CA, Houston, TX, Galveston, TX, Tampa, FLA, Miami, FLA, Charleston, SC, Hampton, VA, Norfolk, VA, Newark, NJ and New York, NY. All other coastal cities that are experiencing MSW disposal problems, and are requiring more electricity and fresh water to meet demands should consider building the proposed integrated facility. Securing additional sources of fresh water is becoming increasingly difficult. In the past as coastal communities ran short of local fresh water supplies to meet demands the solution was to procure water from inland sources. This traditional response is no longer adequate because of competition from growing inland cities which are reluctant to export valuable local fresh water.

If the proposed new facility were to be built in most coastal areas in America the benefits would be gained by a domino or ripple effect far inland. Unlike electricity, water cannot easily and quickly be transported over great distances to where the need is greatest. The smarter tactic is to produce more water where the most population is and the most population is on the coast. Los Angeles and San Diego would reduce by 6.4% their requirements for Colorado River water. This will reduce conveyance losses and make available more water for use from the river by Las Vegas, Phoenix, Tucson, inland agriculture and cattle ranchers. Supporting a common interest, Las Vegas and others may even help finance these proposed facilities in Southern California in exchange for some of California's Colorado River water rights. Southern California would need 1.4% less

electricity to be imported from the northwest. This allows for greater recovery of salmon runs on the Columbia and Snake Rivers because hydroelectricity production could be further decreased. The wetland areas near Pyramid Lake in the Cascades would be revived if Southern California were importing 6.4% less water from the Carson River and Truckee River. Figure 8.1 outlines the effect that increased fresh water availability and electricity on the densely populated coasts will have on inland America. Figure 8.1 is located in Appendix B.

Once Houston withdraws 6.4% less water from the Edwards aquifer then more water from the aquifer will be available for Austin and Dallas. The citrus growers of inland Northern Florida will be the recipients of greater fresh water security when Tampa and Jacksonville place the integrated facility into operation. The same logic for the inland benefits applies to the heavily populated northeastern United States where the potential for electricity generation and desalination for MSW as a fuel is enormous.

Hawaii responding as much of the U.S. may have to has finalized terms of an agreement to build the island's first desalination plant. The plant will be a combined power plant with cogeneration used to produce 300,000 gallons of fresh water per day.[165] In the northwestern United States the Bonneville Power Administration under federal regulations has had a monopoly in the electrical utility industry and has produced an abundance of hydroelectricity. With the recent deregulation of electrical utility suppliers and the mandate to aid salmon migration by replacing hydroelectricity operations the Independent Power Producers (IPP) are free to develop the proposed integrated facility in Washington and Oregon.

If conjunctive use of fresh water were truly understood and utilized the beneficial impact of the proposed facility would occur even further inland as figure 8.1 indicates. The basic idea of conjunctive use is similar to synergy. Conjunctive use yields more fresh water for use because different regions have different wet seasons, different times of snowpack melt, different aquifer recharging rates, different timing of demand for business, agriculture, livestock, recreation and industry. In Washington if Tacoma and Seattle had fresh water interties and practiced conjunctive use then Seattle would have enough water until about the year 2010. Without conjunctive use Seattle will have to develop a major new source of supply, possibly by as early as the turn of the century.[166] Washington state is committed to protecting the environment. The Seattle Water Department has placed the highest priority on protecting the environment when considering alternatives. This along with Seattle's MSW disposal problem make Seattle an excellent city for operation of the proposed facility.

In Texas many serious groundwater problems have developed in recent years. Along the Gulf Coast extensive pumping of groundwater has resulted in saltwater intrusion, threatening water quality in the area. In the central part of the state heavy withdrawals of groundwater have threatened to reduce the flow of rivers, cause further subsidence and have resulted in water shortages. In West Texas and the Texas Panhandle, the most intensively irrigated area in the state, shortage of groundwater has affected the agricultural and industrial sectors of the economy. The gravity of the state's groundwater

problems can be properly understood when one considers that the majority of the state's water needs are met by groundwater supplies.[167] Using the proposed facility in Galveston, Houston and maybe 70 miles off the coast in San Antonio would help supply fresh water to half the state because these three major cities would be withdrawing less from the Edwards Aquifer.

Florida leads the nation in MSW incineration capacity -- with 17,000 tpd -- and continues to add more.[168] Because of Florida's continuing population growth it has a critical need for electricity and is also aggressively pursuing the fastest track possible to the development of large desalination facilities along the gulf coast.[169] The next logical progression will be for Florida to consider a fuel source for heat. The answer is MSW and cogeneration through a power plant.

Boston is spending nearly $1 billion for a new fresh water aqueduct to serve the area.[170] It is quite possible that the money could be better spent, receive greater payback, generate electricity, and solve MSW disposal problems if Boston were to consider the proposed integrated facility.

One more way that the ripple effect of the proposed integrated facility on the coasts will benefit the nation is because electrical generation capacity and fresh water are intricately connected. Inland fossil-fuel, nuclear, and geothermal power plants that provide electricity to coastal cities require very large amounts of water for fuel processing and cooling. Energy resources are used to clean and transport water supplies, in turn, fresh water is withdrawn and consumed to produce energy. During the severe drought in California between 1987 and 1991, large reductions in hydroelectricity production forced electric utilities there to purchase more fossil fuels at an added cost of approximately $3 billion to electricity consumers. One proposal for a small coal-gasification system in Southern California using groundwater for cooling would have led to a drop in local groundwater levels of over 0.5 feet per year.[171] In the coming years, growing demands for water from competing sectors of society and growing populations will place pressures on the water available for energy production. Limitations on the availability of water will restrict the type and extent of energy development. Thus, rational policy makers must integrate these connections. The newly proposed integrated facility will not solve the magnitude of all public works problems, but will produce electricity without using a fuel that requires water for processing. The new facility uses no fresh water for cooling and , in fact, adds 6.4% to fresh water supply availability.

The waste-to-energy (WTE) base in the United States is strengthening every day. Many coastal states are already operating large WTE plants and are not taking advantage of the valuable waste heat available that could be used through cogeneration for desalination. To mention a few of the larger WTE plants, there is a 1,440 tpd facility serving Union County, New Jersey, a 1,200 tpd day facility serving Lee County, Florida, a 990 tpd facility serving Onondaga, New York, and a 1,800 tpd facility in Montgomery County, Maryland. Each of these plants are ideally suited for the addition of desalination units to produce fresh water from wasted heat.

CHAPTER NINE
COMMENTARY

A municipal solid waste incinerator, steam electric generator, and ocean water desalination unit integrated facility has been designed for a city of population 100,000. This facility has the capability of reducing the municipal waste for landfill by at least 90%, providing 1.5% of the city's electricity, and furnishing 7% of the city's fresh water. Analysis has shown a cost/benefit ratio of about 1.5.

Public works departments must rethink basic strategies. America is actively pursuing engineering solutions for ways to more effectively dispose of MSW, increase production of electricity and to increase fresh water supplies to meet demands. As of July, 1995 America's population was 262,355,000 and continues to steadily grow.[172] Public works utility issues must be seriously addressed prior to the end of this century. Traditional methods of meeting public works requirements are becoming less of an option. The challenge is to find the most economically sensible means to dispose of MSW, generate electricity, and provide fresh water while striking a balance that will not cause an environmental overload. Nonstructural actions for utilities management should be employed first as much as is practical. Source-reduction and recycling are excellent for lessening the daily volume of MSW discarded. Conservation and other energy saving techniques work well for reducing electricity demands. Conservation, water reuse and conjunctive use are essential for ensuring that adequate fresh water supplies are available for all M & I consumption. Even the most well orchestrated nonstructural practices have limitations and only help to stretch public works utilities, but cannot solve present and future shortages. In 1993, 207-million tons of MSW was discarded in the USA. The EPA predicts that even with significant source-reduction efforts, the total amount of MSW generated is expected to increase to 218-million tons by the year 2000 because of consumer demands and population growth.[173]

Waste-to-Energy technologies have become quite refined and the practice of using MSW as fuel source to produce electricity is being used more often in densely populated regions. There is room for improvement in that WTE plants do not make full use of the caloric value in MSW because most of the exhaust heat from the TGs is wasted. Water resources managers are more frequently choosing desalination as an alternative for increasing fresh water supplies today and like the fact that the product is the purest form of fresh water. The expanded benefits from desalination through conjunctive use are clearly an avenue of great potential. The primary reason that desalination is not chosen more often is that desal units require a constant source of heat to operate. Continually having to supply fuel for operation is viewed as an economical disadvantage charged against desalination. A few desal facilities in operation around the world do use heat from extraction/admission-condensing units in a power plant arrangement, but are not solving the MSW disposal problem and use a condensing type turbine which still rejects large amounts of heat directly to the environment. A back-pressure turbine pure cogeneration

cycle without any condensing power generation is much more energy efficient. The proposed integrated facility combines WTE plants with desal units through true cogeneration to create the most energy efficient engineering design. While the proposed integrated facility does not solve all utilities problems faced by the nation's public works infrastructure it does provide significant benefits that are greater than status quo. The new facility eliminates 94.95% of all MSW landfilling, reliably provides nearly 1.5% of electricity consumed by the nation and up to 7% of M & I fresh water required regardless of rainfall. Further increases in electricity and water supplied are gained by eliminating conveyance losses. The newly proposed integrated facility is certainly economically competitive and when all impacts are evaluated this integrated public works facility is the best for protecting the environment.

One major key to the potential future development of this facility is that separate departments within public works must get beyond the "my camp/organization" mentality. The standard modus operandi throughout the USA is that each different utility department or agency tends to tackle complex issues they face only from within and limited to the perspective and requirements of their department or agency alone. The traditional solution involving independent action by individual agencies is no longer efficient. For example, desalination is normally considered by water departments and penalized for the cost of fuel, meanwhile solid waste departments are paying by the ton to have MSW disposed of. If the two were to synergize and realize that the desal unit could actually receive its fuel free or even be paid to accept fuel the entire solution to both department's needs would become much more achievable. For electricity generation, fossil fuel, hydropower, and nuclear fuel are each having big problems for sustained usage. According to the American Petroleum Institute oil imports to the United States reached a record 49.5% of consumption in 1993 while domestic oil production sank to a 35-year low.[174] The high costs of nuclear power coupled with the low-probability, but high-consequence accidents associated with nuclear plants has left it as the least preferred method of producing electricity. Other than NO_x emissions natural gas used as a fuel is an outstanding solution while supplies last, but natural gas power plants do not also dispose of MSW. Integrated decision making to reflect the interrelationships between utilities, other services and growth is a definite necessity for defining the nation's collective future. Progress towards a better understanding of these relationships and towards a more integrated approach has been made in this thesis.

Many of the approaches and solutions the nation has used in the past to meet the challenge of MSW disposal, providing clean water, and producing electricity to meet the nation's needs won't work, or won't be effective, in the future. The nation still needs to develop water and power supplies to meet needs of the growing population, but new and innovative solutions for meeting these needs will be required. The federal government has taken a position that financially encourages developers to present innovative ways to dispose of MSW, generate electricity, and extend the use of available fresh water supplies. There are seven billion dollars of DOE federal funds marked to match $1 to each $3 expended by developers on worthy public works demonstration projects,

especially those that view public works in its entirety.[175] The newly proposed integrated facility in this thesis is an ideal candidate to receive federal funds for a pilot project. This, first of its kind, facility presents a rational solution to solving public works problems, directly enhances the National Economic Development (NED) agenda, reduces harm to the environment, and helps maintain America's global competitiveness. Society will benefit by selecting this project as a long-term commitment. It will result in more efficient resource management and less overall environmental impact when land, water, and air resources are evaluated concurrently and trade-offs are considered.

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APPENDIX A

NOMENCLATURE

A/E	Air Ejectors or Architect/Engineer
As	Arsenic
Aux	Auxiliary
AVE	Average
Bbl	Bulk Barrel
b/c	Benefit/Cost
Be	Beryllium
BLR	Boiler
Btu	British Thermal Units
CCF	100 Cubic Feet
cd	Cadmium
cf	Cubic Feet
CLNG	Cooling
COND	Condenser
CO	Carbon Monoxide
CO_2	Carbon Dioxide
cy or CY	Cubic Yard
Desal	Desalination
DOE	Department Of Engery
Dr.	Doctor
dy	Day
EDR	Electrodialysis Reversal
eff	Efficiency
EIS	Environmental Impact Statement
EPA	Environmental Protection Agency
ESP	Electrostatic Precipitator
EVAP	Evaporator
°F	Fahrenheit
FF	Fabric Filter
ft	Feet
FW	Feed Water
gal.	Gallon
GAO	General Accounting Office
GITMO	Guantanamo Bay, Cuba, Naval Facility
GNP	Gross National Product
gpd	Gallons Per Day

Nomenclature Continued

H_2SO_4	Sulfuric Acid Mist
h	Enthalpy
HBr	Hydrogen Bromide
HCL	Hydrogen Chloride
HDPE	High-Density Polyethylene
HF	Hydrogen Fluoride
Hg	Mercury
hr	Hour
hrs	Hours
HSE	House
I	Electrical Current
IPP	Independent Power Producer
JTF	Joint Task Force
Km	Kilometer
KW	Kilowatts
KWhs/KWhr	Kilowatt Hours/Kilowatt Hour
l	Liter
lb	Pound
lbs	Pounds
LOLP	Loss Of Load Probability
LP	Low Pressure
m^3	Meters Cube
m	Mass Flow Rate
m	Meter
M & I	Municipal and Industrial
Max	Maximum
MBtu	Million British Thermal Units
MCC	Motor Control Center
mg	Milligram
mgd or MGD	Million Gallons Per Day
MGMT	Management
min	Minute or minimum
mpg	Miles Per Gallon
MOV	Motor Operated Value
mph	Miles Per Hour
MSW	Municipal Solid Waste
MW	Megawatt
MWhrs	Megawatt Hours
n	Polytropic Exponent
NAFTA	North American Free Trade Agreement

Nomenclature Continued

NAVFAC	Naval Facilities Engineering Command
NCG	Non-Condensible Gases
ND	No Detection Limit
NED	National Economic Development
ng	Nanogram
NIMBY	"Not In My Backyard"
NO_x	Nitrogen Oxides
NO	Normally Open
NR	Not Reported
NRC	Nuclear Regulatory Commission
O & M	Operation And Maintenence
OPEC	Organization of Petroleum Exporting Countries
P	Power
Pb	Lead
PF	Power Factor
pH	Acidity
plt	Plant
PM	Particulates
POL	Petroleum, Oil, and Lubricants
POP	Population
ppm	Parts Per Million
psi	Pounds Per Square Inch
psia	Pounds Per Square Inch Absolute
psig	Pounds Per Square Inch Gage
PT	Pressure Transmitter
Pwr	Power
R	Electrical Resistances or Gas Constant
RCI	The Federal Rapid Commercialization Initiative
RCRA	Resource Conservation and Recovery Act
R & D	Research and Development
R/O	Reverse Osmosis
S	Entropy
Sb	Antimony
SDA	Spray-Dry-Absorber
S.G.	Specific Gravity
SNCR	Selective Non-Catalytic Reduction
SO_2	Sulfur Dioxide
SO_x	Sulfur Oxides
sq	Square
sq mi	Square Mile

Nomenclature Continued

sq yds	Square Yards
stm	Steam
T	Tons or Temperature
TCLP	Toxicity Characteristic Leaching Procedure
TDS	Total Dissolved Solids
TG	Turbine-Generator
tpd	Tons Per Day
TVA	Tennessee Valley Authority
U_3O_8	Nuclear Fuel
UF_6	Nuclear Fuel
U.S.	United States
USA	United States of America
V	Volume
VOCs	Volatile Organic Compounds
vs. or Vs.	Versus
wk	Week
WTE	Waste-To-Energy
WTR	Water
x	Steam Quality or Any Variable
yr	Year

APPENDIX B

DRAWINGS

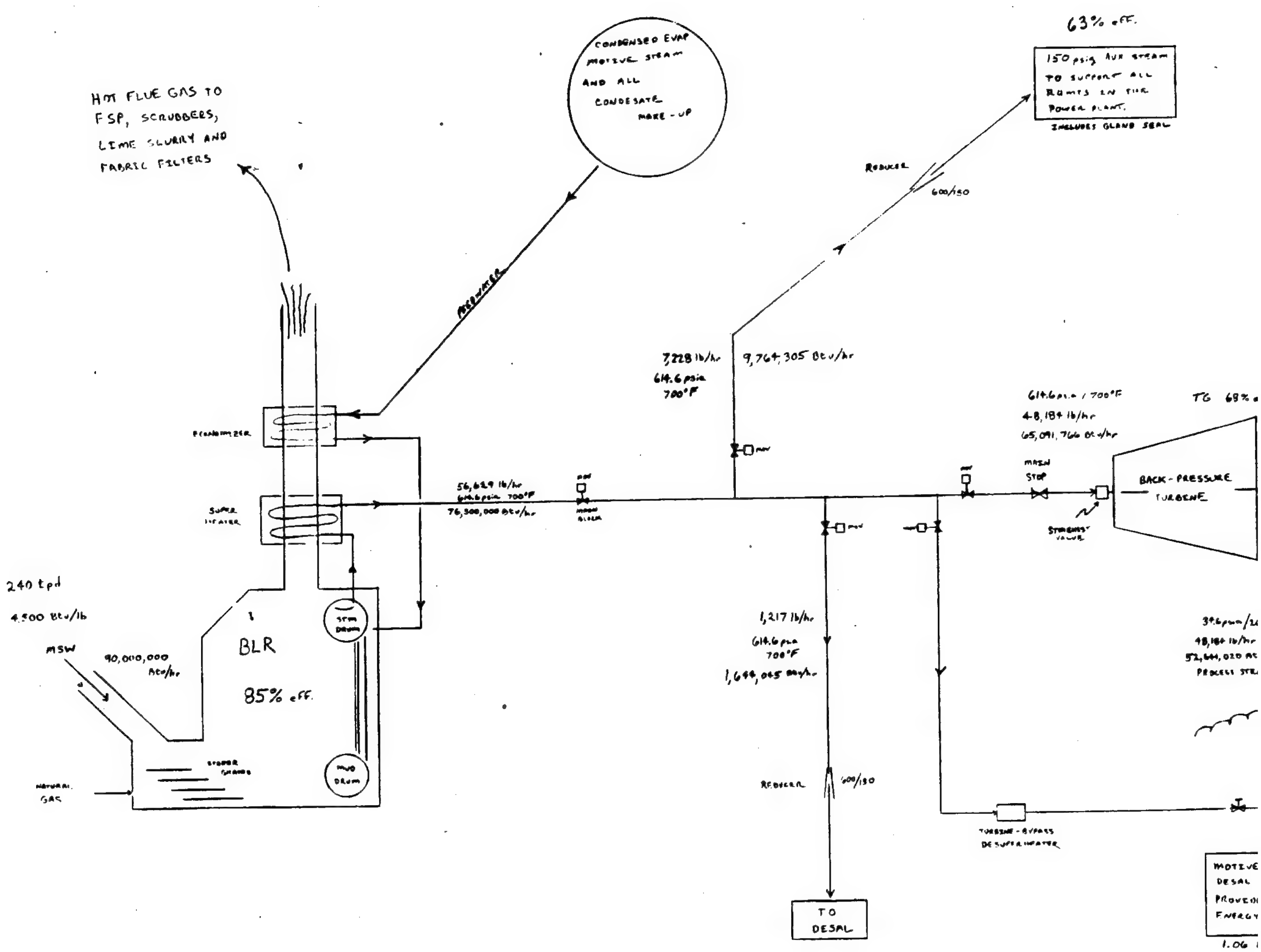
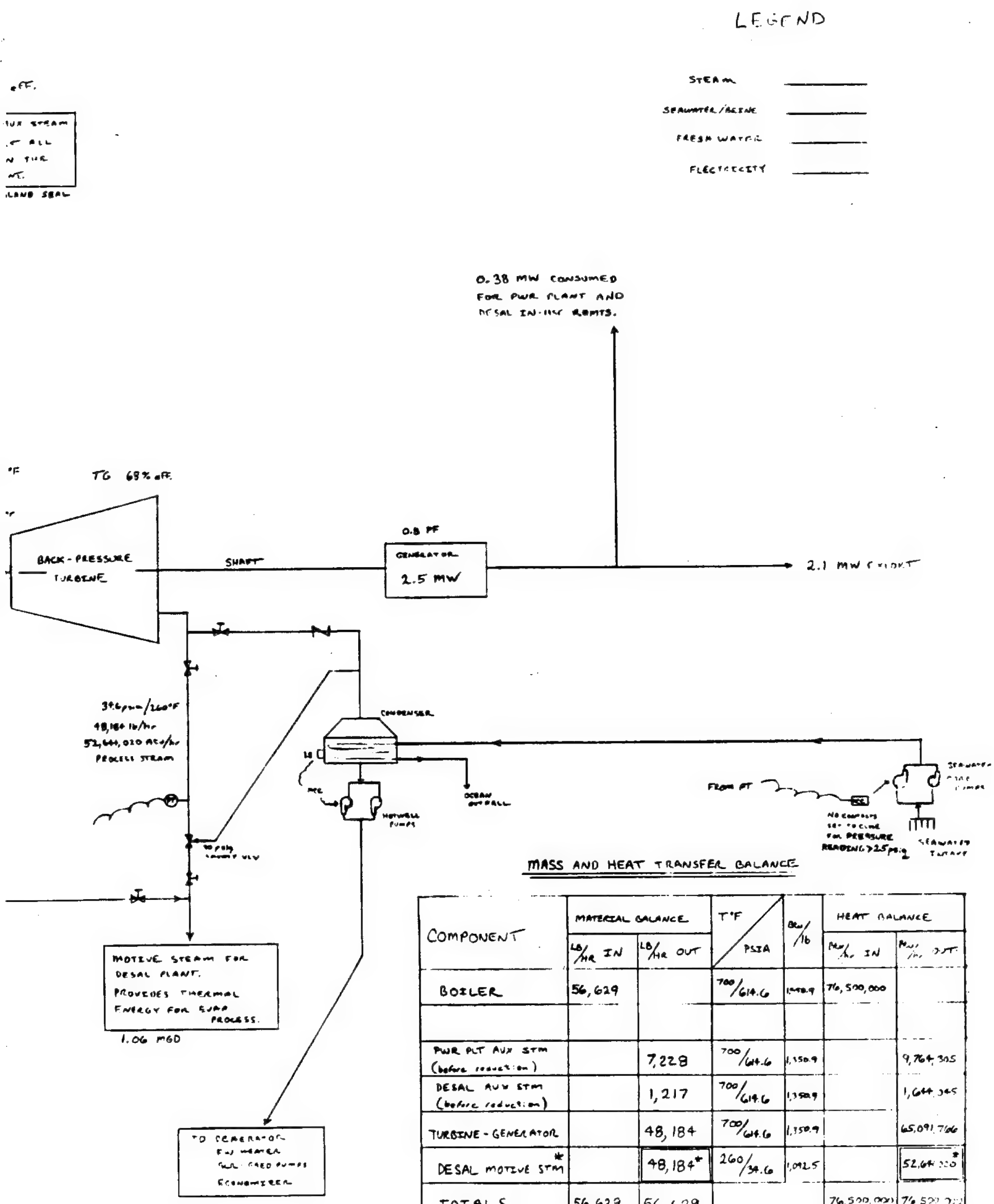


FIGURE 5.1 WASTE-TO-



MASS AND HEAT TRANSFER BALANCE

COMPONENT	MATERIAL BALANCE LB/HR IN	MATERIAL BALANCE LB/HR OUT	T°F / PSIA	Btu/lb	HEAT BALANCE Btu/hr IN	HEAT BALANCE Btu/hr OUT
BOILER	56,629		700/614.6	1,350.9	76,500,000	
PWR PLT AUX STM (before reduction)		7,228	700/614.6	1,350.9		9,764,305
DESAL AUX STM (before reduction)		1,217	700/614.6	1,350.9		1,644,345
TURBINE-GENERATOR		48,184	700/614.6	1,350.9		65,091,766
DESAL MOTIVE STM *		48,184*	260/34.6	1,092.5		52,644,020*
TOTALS	56,629	56,629			76,500,000	76,500,000

* NOT INCLUDED IN PWR PLANT BALANCE. USED FOR DESAL UNIT (IN) BALANCE.

-TO-ENERGY PLANT

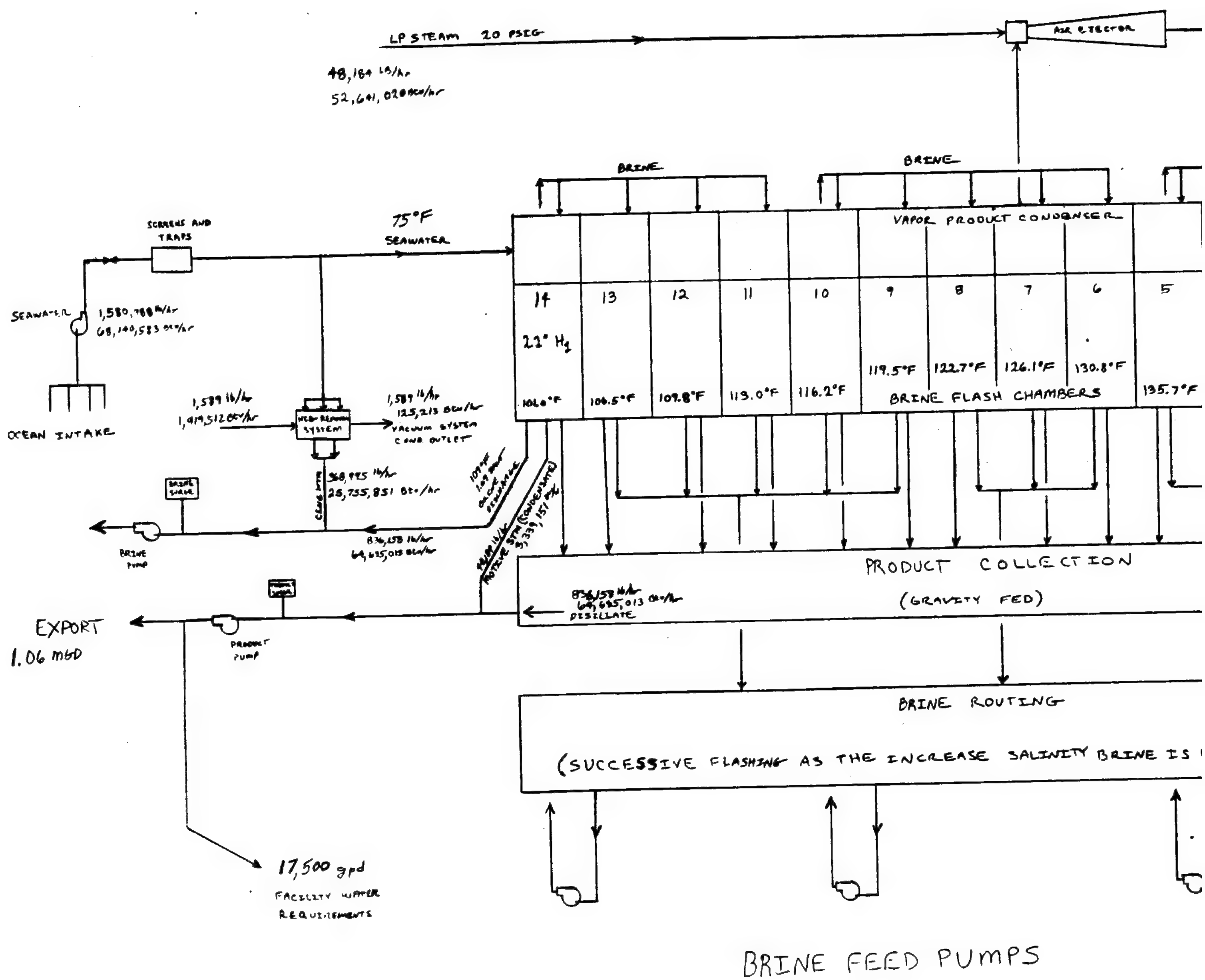
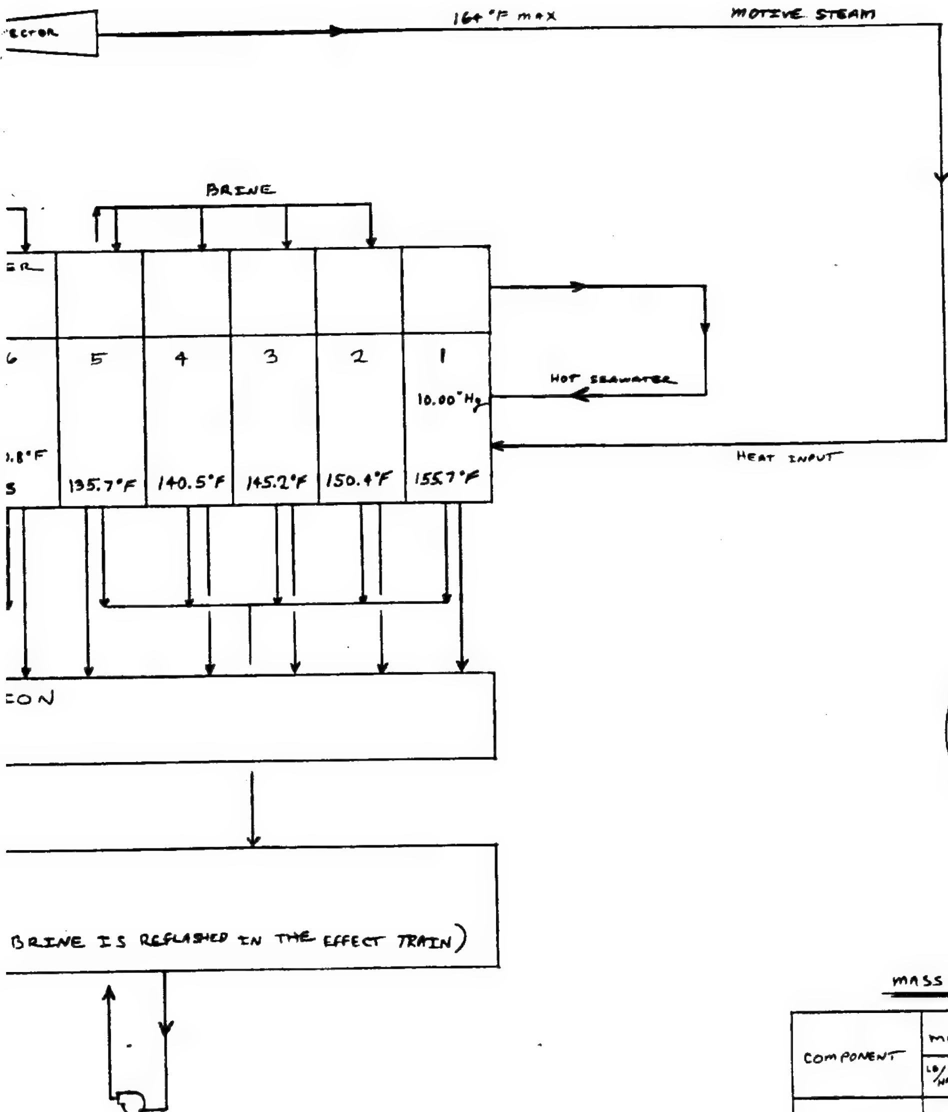
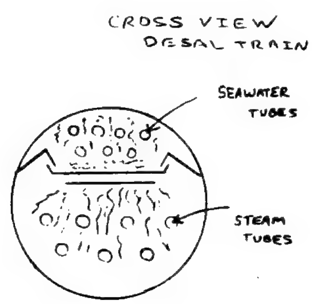


FIGURE 5.2 DESALINATI



RADIATION AND VENTILATION HEAT LOSSES
545,512 Btu/hr



LEGEND

STEAM
SEAWATER/BRINE
FRESH WATER
ELECTRICITY

MASS AND HEAT TRANSFER BALANCE

COMPONENT	MATERIAL BALANCE		T°F / PSIA	BTU/LB	HEAT BALANCE	
	LB/HR IN	LB/HR OUT			BTU/HR IN	BTU/HR OUT
SEAWATER	1,580,988		75/29.6	43.1	68,140,583	
MOTIVE STEAM (HEAT)	48,184		260/34.6	1,092.5	52,641,020	
AUX STM (A/E)	1,589		382.4/164.6	1,208	1,919,512	
MOTIVE STEAM (CONDENSATE)		48,184	101/65	69.3		3,339,151
DISTILLATE		375,835	107/43.4	75.3		28,300,375
BRINE OUTFALL		836,158	109/26.6	77.3		64,635,013
CONDENSATE CLNG SEAWATER OUT		369,995	101.5/26.6	69.8		25,[illegible]
AUX (A/E) CONDENSATE		1,599	110.5/65	78.8		125,213
RADIATION + VENTILATION						545,512
TOTAL	1,630,761	1,630,761			122,701,115	122,701,115

ATION UNIT

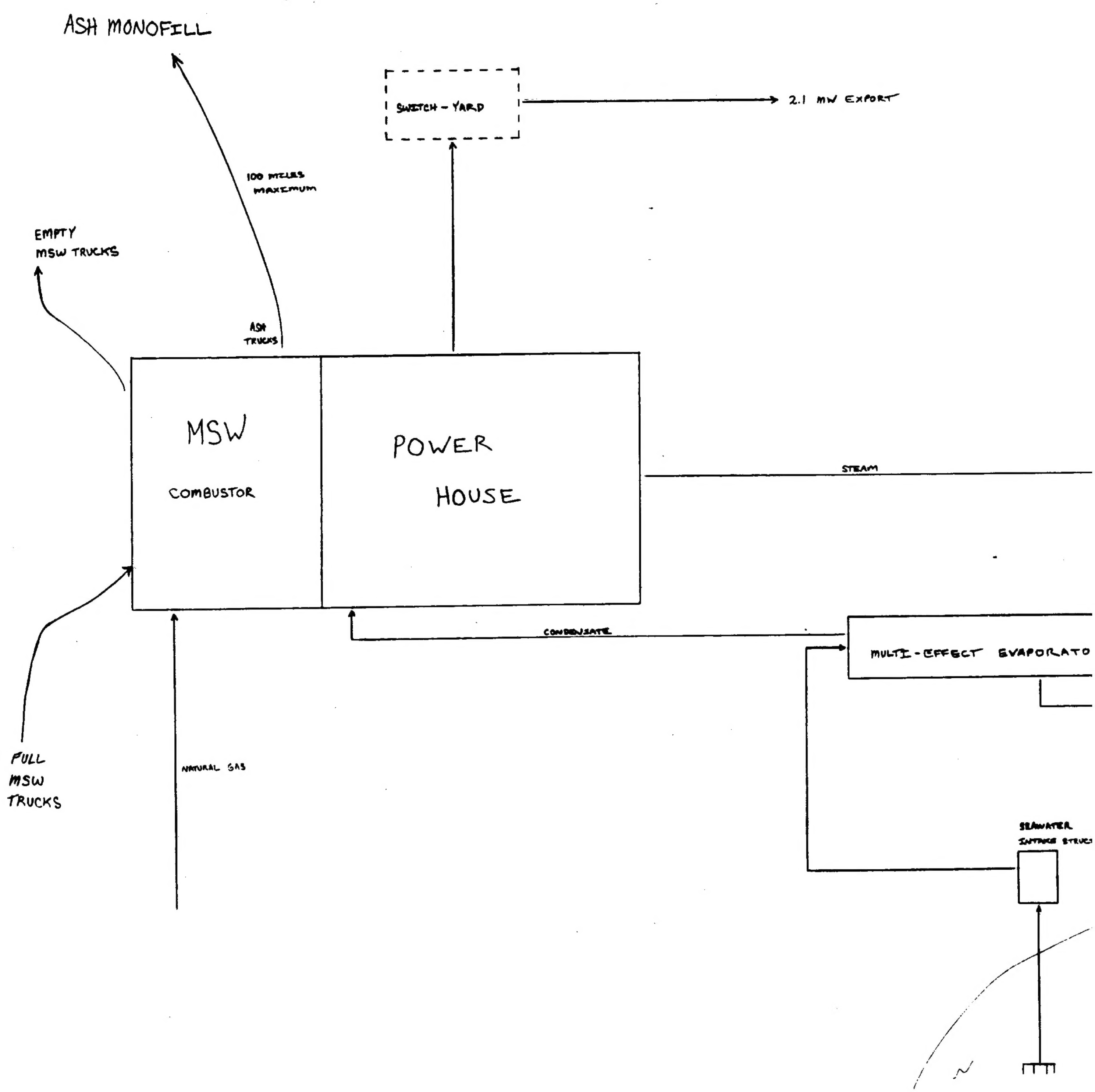
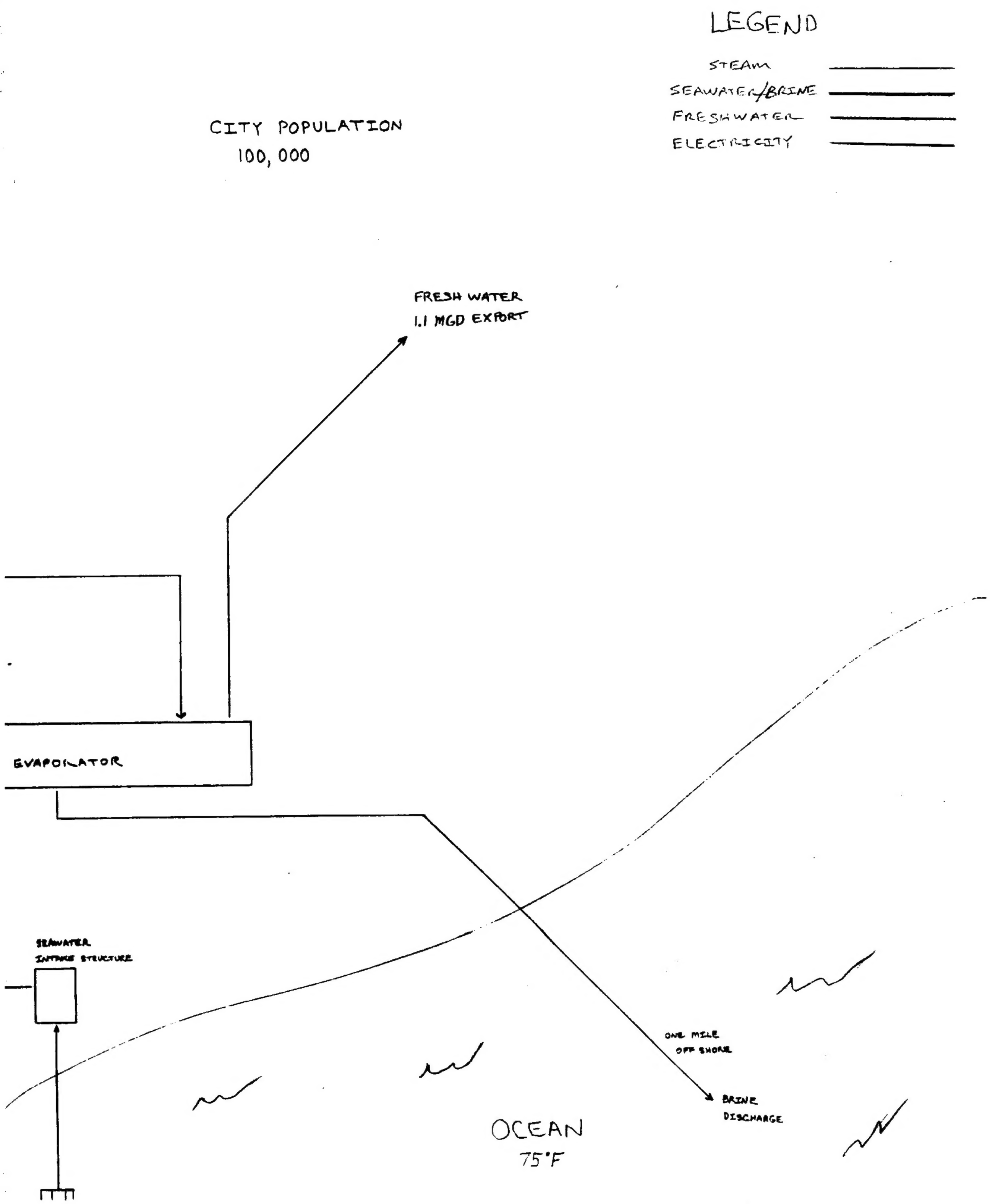


FIGURE 5.3 PLAN VIEW O



W OF INTEGRATED FACILITY

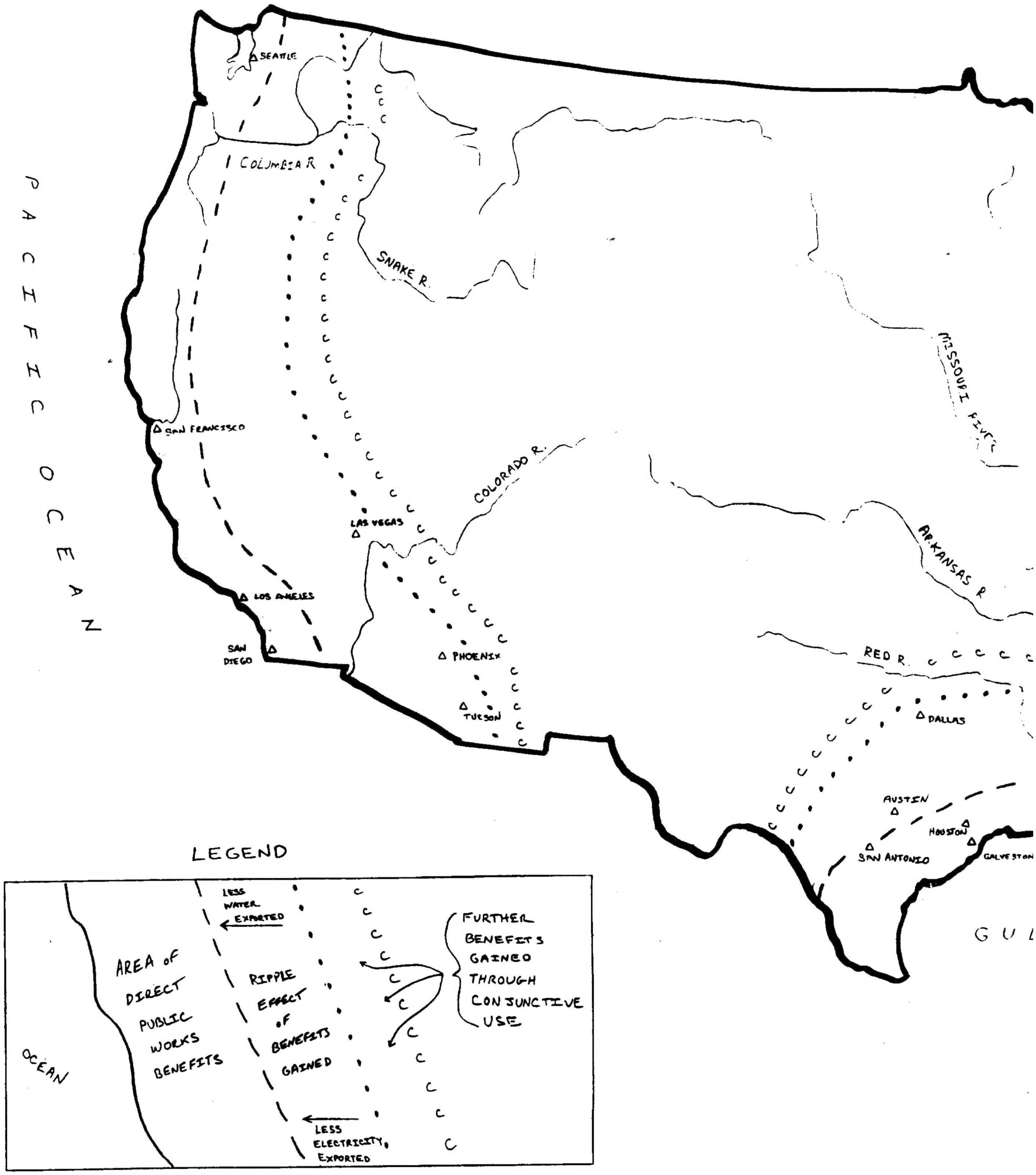
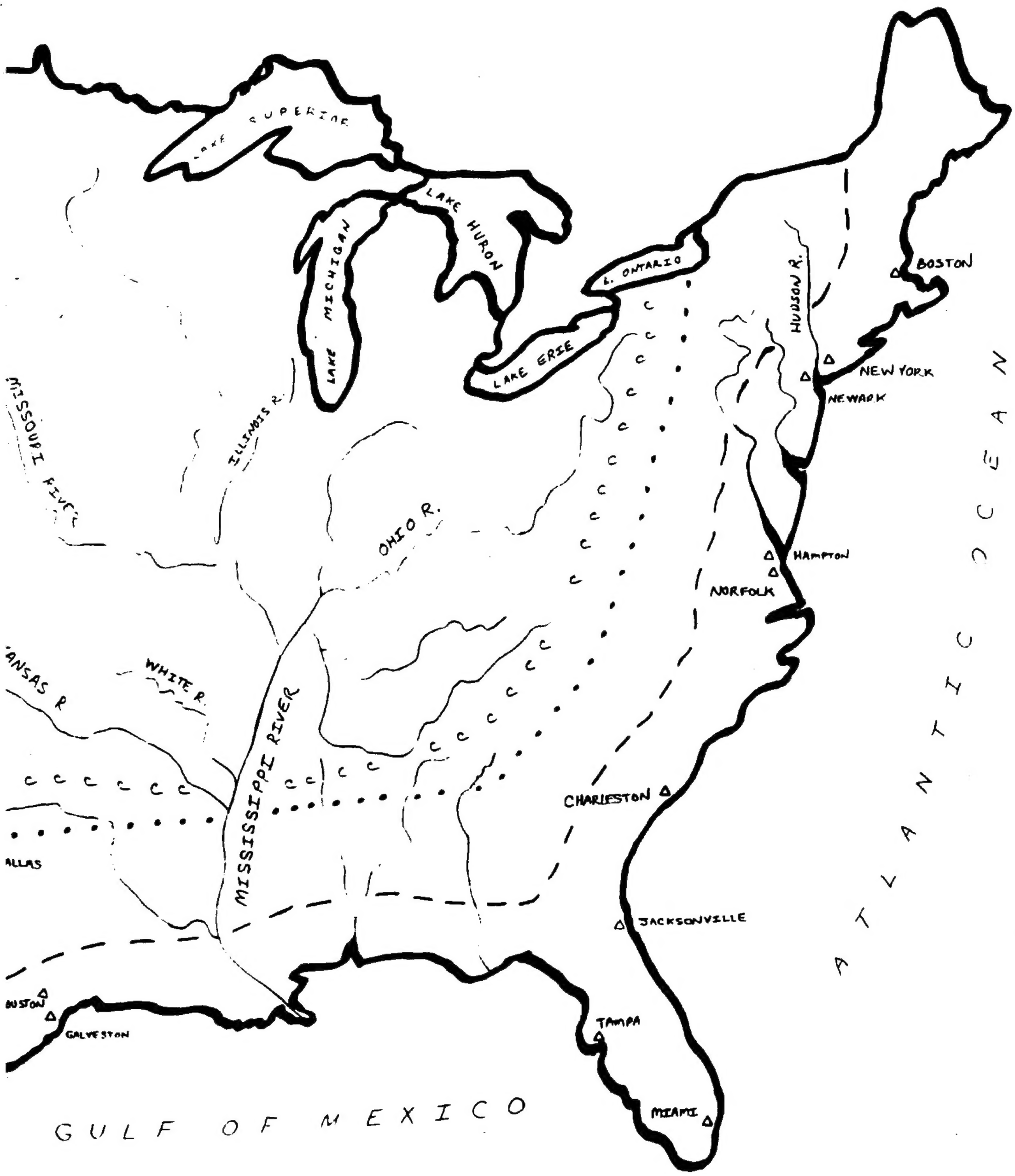


FIGURE 8.1 DEMOGRAPHIC BENEF



ENEFITS FOR THE NATION